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Performance Effectiveness Testing of the Expeditionary Fire Suppression System; Phase II

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On behalf of AAC/WMO, the Air Force Research Laboratory evaluated the Expeditionary Fire Suppression System (EFSS). The EFSS is a modified-commercial, combined-agent system that can be mounted on an Air Force P-20 truck or heavy duty, general purpose truck. The preliminary tests and evaluations of the EFSS 5120-7 to determine its effectiveness included foam and dry chemical flow rates; foam throw distance and foam expansion ratio. The overall performance of the EFSS was good. Expansion ratio, throw distance and flow rates were all within acceptable ranges. The majority of the problems experienced with the EFSS 5120-7 were a result of the regulators, which could easily be resolved with filter to remove debris from the compressed air. The foam system needs to be evaluated to determine why that part of the system is activated when the dry chemical system is being discharged. The dry chemical system is performing less than optimal, with approximately 50% of the total dry chemical volume not being discharged with the given volume of compressed air.

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Abstract

On behalf of AAC/WMO, the Air Force Research Laboratory evaluated the Expeditionary Fire Suppression System (EFSS). The EFSS is a modified-commercial, combined-agent system that can be mounted on an Air Force P-20 truck or heavy duty, general purpose truck. The preliminary tests and evaluations of the EFSS 5120-7 to determine its effectiveness included foam and dry chemical flow rates; foam throw distance and foam expansion ratio. The overall performance of the EFSS was good. Expansion ratio, throw distance and flow rates were all within acceptable ranges. The majority of the problems experienced with the EFSS 5120-7 were a result of the regulators, which could easily be resolved with filter to remove debris from the compressed air. The foam system needs to be evaluated to determine why that part of the system is activated when the dry chemical system is being discharged. The dry chemical system is performing less than optimal, with approximately 50% of the total dry chemical volume not being discharged with the given volume of compressed air.

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Summary

Introduction

On behalf of AAC/WMO, the Air Force Research Laboratory evaluated the Expeditionary Fire Suppression System (EFSS). The EFSS is a modified-commercial, combined-agent system that can be mounted on an Air Force P-20 truck or heavy duty, general purpose truck. The system is designed to be a lightweight yet powerful expeditionary fire fighting capability that is ruggedized for air-insert and/or air-delivery and capable of extinguishing a 7000 ft2 JP-8 pool fire within 45 seconds of fire fighting. The system uses AFFF-based compressed air foam and PKP dry chemical. Other features include: operability in separate and combined application with concentric fixed-orifice nozzle turret, handline in austere deployed environments (such as, but not limited to extreme weather), and options for a remote-controlled turret and a remote sensing/fire suppression capability. Also included is a multi-platform skid unit for mounting.

Purpose

The purpose of this evaluation was to conduct a fire fighting effectiveness (Phase I) and performance effectiveness (Phase II) of modified-commercially available EFSS, using the Air Force Research Laboratory (AFRL) Combined Agent Fire Fighting System (CAFFS) as a baseline (See DTIC report AFRL-ML-TY-TR-2004-4511, Performance Evaluation of the Combined Agent Fire Fighting System).

Scope

The preliminary tests and evaluations of the EFSS 5120-7 to determine its effectiveness included:

- Foam and dry chemical flow rates for both the handline and turret.
- Foam throw distance for both the handline and turret.
- Foam expansion ratio for both the handline and turret operation.

Results

The overall performance of the EFSS was good. Expansion ratio, throw distance and flow rates were all within acceptable ranges. The majority of the problems experienced with the EFSS 5120-7 were a result of the regulators. While the manufacturer replaced the initial regulators with higher quality components, significant problems were still encountered. AFRL suggested the installation of filters in series with the regulators to keep debris from fouling the regulators. Extensive experience with other systems that operated with compressed air have shown that debris entrained in the compressed air during reservicing can cause complete failure of the regulators if the air is not filtered sufficiently.

After the regulators were changed the previous problems continued and new problems surfaced, such as unexplained drops in air tank pressure and pressure build-up in foam tank that resulted in the pop-off valve blowing. During each test of the dry chemical system, the pressure at the dry chemical tank was readjusted to 225 psi per manufactures specification. Pressures climbed past the 225 psi set point on the dry chemical tank resulting in the pop-off safety valve blowing at 250 psi. Pressure drops at the foam and dry chemical air tanks occurred that could not be explained. The foam air tank decreased in pressure during test even though no foam was being flowed.

During turret full tank dry chemical disbursement, the high pressure air volume was not sufficient to discharge the 500 lb capacity of the tank. This resulted in more than 50% of the dry chemical left in the tank unusable.

Conclusions

During several tests, the pop off valve did not activate at the set pressure. This valve is the only safety device installed on the system to relieve pressure in the event of regulator failure. AFRL had to manually shut down the EFSS during testing to avoid over pressuring the foam and dry chemical tanks.

The foam system needs to be evaluated to determine why that part of the system is activated when the dry chemical system is being discharged. According to the manufacturer, the systems are plumbed as stand alone and should not operate unless the tank is charged and agent is being flowed.

Less than 50% of the total dry chemical volume was discharged with the amount of compressed air available during turret operations.

Recommendations

The function and safety of the EFSS relies heavily on the performance of the regulators. Experience during testing has shown that faulty regulators make the system inoperable from a reliability and safety standpoint. High quality regulators should be installed on the system along with a set of filters to prevent debris from fouling the components. Regulator manufacturers recommend that regulators be rebuild every year. Experience in extreme environments, in particular sand, dust and dry chemical, indicates that more frequent overhauling is necessary to assure optimal performance.

The pop off valves should be checked for rating and proper function to prevent potential failure of the agent tanks due to over pressurization.

Additional safety measures may need to be taken since the regulators and pressure relief valves both failed on at least one test.

Complete a plumbing diagram so that each agent system can be evaluated and problems remedied.

The volume of compressed air need to drive the dry chemical turret operation needs to be recalculated.

1 Background

1.1 Introduction

The Air Force is evaluating a Expeditionary Fire Suppression System (EFSS). The EFSS is envisioned to be a modified-commercial, combined-agent dispensing system that can be mounted on an Air Force P-20 truck or heavy duty, general purpose truck (Figure 1). The system is designed to be a lightweight yet powerful expeditionary fire fighting capability that is ruggedized for air-insert and/or air-delivery and capable of extinguishing a 7000 ft2 JP-8 pool fire within 45 seconds of fire fighting. The system uses AFFF-based compressed air foam and PKP dry chemical. Other features include: operability in separate and combined application with concentric fixed-orifice nozzle turret, handline in austere deployed environments (such as, but not limited to extreme weather), and options for a remote-controlled turret and a remote sensing/fire suppression capability. Also included is a multi-platform skid unit for mounting.

Figure 1. The Expeditionary Fire Suppression System Mounted on a P-20.

1.2 Purpose

The purpose of this evaluation is to conduct a fire fighting (Phase I) and performance effectiveness (Phase II) of modified-commercially available EFSS, using the Air Force Research Laboratory (AFRL) Combined Agent Fire Fighting System (CAFFS) as a baseline (See DTIC report AFRL-ML-TY-TR-2004-4511, Performance Evaluation of the Combined Agent Fire Fighting System).

1.3 Scope

Due to problems with regulators sticking and irregular gauge readings encountered early in testing, pressure regulators were changed on the foam tank, dry chemical tank and injection air. AFRL suggested switching to a regulator with a higher flow coefficient and adding filters before the regulators to prevent debris from fouling the regulators. New regulators with high flow coefficients were installed but the filters were not. Tests done prior to this were repeated. The results presented below show both the tests completed before and after the regulators were changed.

The preliminary tests and evaluations of the EFSS 5120-7 to determine its effectiveness include:

- Foam and dry chemical flow rates for both the handline and turret.
- Foam throw distance for both the handline and turret.
- Foam expansion ratio for both the handline and turret operation.

2 Methods and Procedures

2.1 Foam test procedures

- Foam was flow in 30-second intervals with the handline until agent was expended. The periods between flow intervals started with five seconds and increased in increments of five until the test ended. Foam flow, injection air, system pressure, foam tank pressure and pressure at the nozzle were recorded. Additional measurements included foam expansion ratio and throw distance. This test was repeated for the turret.
- A full tank of foam was flowed with the handline. Expansion ratio and throw distance were measured. This test was repeated for the turret.

2.2 Dry Chemical test procedures

- Dry chemical was flowed in 20-second intervals with the handline until agent was expended. The periods between flow started with 10 seconds and increased in increments of 10 for the test duration. Dry chemical flow rate, system pressure, dry chemical tank pressure and pressure at the nozzle were measured. This test was repeated for the turret.
- A full tank of dry chemical was flowed to determine changes in flow rate from full to empty tank. This was completed for both the handline and turret.

2.3 Foam and Dry Chemical test procedures

- Foam and dry chemical were flowed for 30 seconds with the handline. Flow rate, injection air, system pressure, foam tank pressure and pressure at the nozzle were recorded. Additional measurements included throw distance. This test was repeated for the turret.

2.4 Data Acquisition

Equipment and software for acquiring, recording, and manipulating data included a National Instruments Data Acquisition System (DAQ), Lab View software, Excel and a Dell Computer with monitor. Instrumentation equipment included an Omega LCCB 2K load cell, for measuring the weight of the skid unit and Omega PX605-300GI Pressure transducers for measuring the pressure of the flow at the turret and handline (Table 1).

Table 1. Instrumentation List

Designation	Location	Range	Comments
HPT-1	Foam Air Tank	0-3000 psi	Omega PX605-3KGI
HPT-2	Dry Chem Air Tank	0-3000 psi	Omega PX605-3KGI
PT-3	Foam Handline	0-300 psi	Omega PX605-300GI
PT-4	Dry Chem Handline	0-300 psi	Omega PX605-300GI
PT-5	Dry Chem Tank	0-300 psi	Omega PX605-300GI
PT-6	Mix Valve	0-300 psi	Omega PX605-300GI
PT-7	Foam Tank	0-300 psi	Omega PX605-300GI
PT-8	Dry Chem Turret	0-300 psi	Omega PX605-300GI
PT-9	Foam Turret	0-300 psi	Omega PX605-300GI
FM-1	Foam Flow	0-180 gpm	Omega FTB-908
FM-2	Injection Air Flow	0-180 cfm	Omega FTB-935
LC-1	Dry Chemical Weight	0-2000 lbs	Omega LCCB 2K Scale factors to compensate for tank location relative to pivot and load cell
TC-1	Temperature @ Mix Valve	-40 to 120 deg F	Omega T (blue)-type thermocouple

3 Results

3.1 System Performance for Foam Handline

The foam tank and injection air pressure were set to the manufactures specifications of 185 and 190 psi for all foam testing both with the original and replacement regulators.

3.1.1 System Performance for Foam Handline Intermittent Disbursement

Figure 2 shows the pressures and flow rates prior to the change of regulators. The foam tank pressure, during flow and non-flow periods increased over the duration of the test. During flow periods the foam tank pressure was approximately 30-40 psi below the set pressure of the regulator (138 psi, phase 1, to 151 psi, phase 5). The injection air pressure prior to flow was 180 psi, although it was set before the test to 190 psi. The injection air stayed relatively constant during flow periods, between 175 and 178 psi. The pressure at the handline functioned normally at 25 psi during flow periods and 175 psi during non-flow periods. The foam flow rate was approximately 35 gpm for each phase. No injection airflow was recorded for this test. The injection air flow meter was tested and a visual inspection at the nozzle was performed. This indicated a flow less than 2.5 cfm, which was the low-end of the flow meter and confirmed that the flow meter was working correctly and little air was coming out of the nozzle.

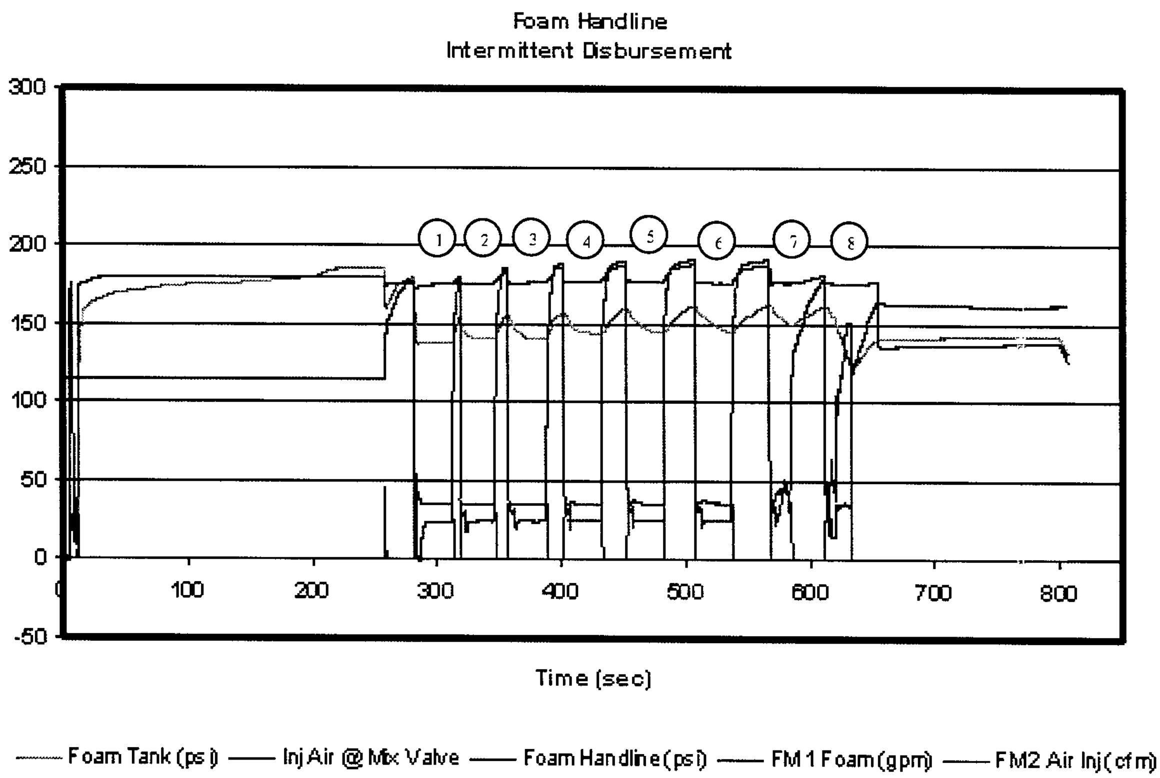

Figure 2. Handline Foam Flow and Pressure Data, Intermittent Disbursement.

After the regulators were changed problems continued with the regulation of pressures and the system charging slowly. Also, new problems developed, such as pressure build-up and sudden pressure loss at the foam air tank developed during flow. The same manufacturer settings were kept after the new regulators were installed (foam at 185 psi, injection air at 195 psi). Figure 3 shows the pressures and flow rates after the regulators were changed. Prior to this test, neither the foam tank nor the injection air pressures were reset. When testing began, the foam tank and injection air pressures were 154 and 160 psi respectively. The foam tank pressure during flow periods increased over each phase with a beginning pressure of 129 psi and an ending pressure of 194 psi. The pressure of the foam tank during non-flow periods increased from 151 psi, phase 1, to 250 psi, phase 6. The injection air pressure during flow increased from 114 psi, phase 1, to 188 psi, phase 6. The pressure during non-flow periods also increased substantially from approximately 149 psi, phase 1, to 265 psi, phase 6. During phase 6 the pop-off valve blew on the foam tank. The foam handline pressure continued to rise during each phase of the test between 18 to 66 psi. During non-flow periods the pressure climbed from 157 psi, phase 1, to 233 psi, phase 6. This indicated that the foam and injection air regulators were not functioning correctly. The flow meter showed a steady increase in the flow rate as the pressure in the tank and injection air increased. The gpm increased from an average of 36 gpm, phase 1, to an average of 42 gpm, phase 5. No injection air data was recorded during this test. The pop-off valve (set to 250 psi) blew when the foam tank and injection air pressures reached 249 and 264 psi, respectively.

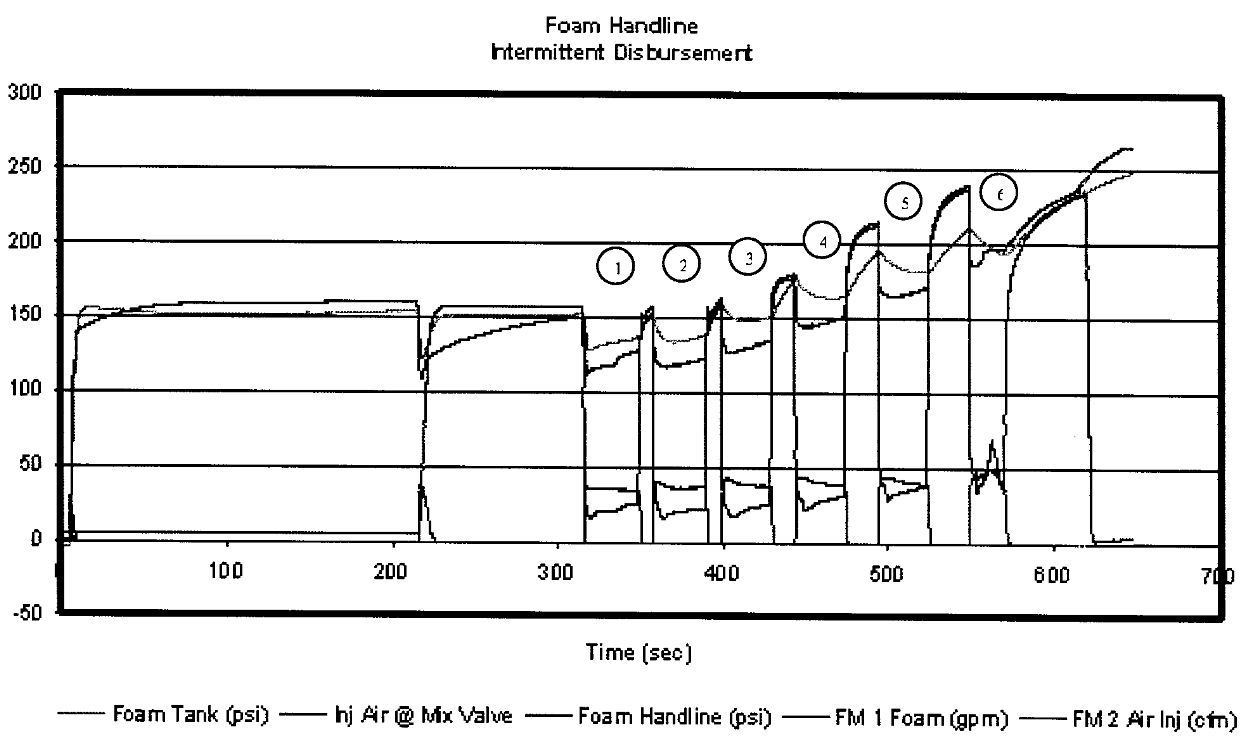

Figure 3. Handline Foam Flow and Pressure Data, Intermittent Disbursement.

3.1.2 System Performance for Foam Handline Full Tank Disbursement

The pressures and flow rates prior to the change of regulators are shown in Figure 4. When the foam was discharged, the foam tank pressure decreased to 176 psi and the injection air pressure decreased to 136 psi. The pressure in the foam tank showed a slight decline in pressure toward the end of the test. For this test, the regulator was functioning normally and maintaining pressure close to the set point. The pressures at the end of the test for the foam tank and injection air were 169 and 129 psi. The handline pressure was maintained at an average pressure of 24 psi. The foam flow was maintained at approximately 34 gpm throughout the test. No injection airflow was measured.

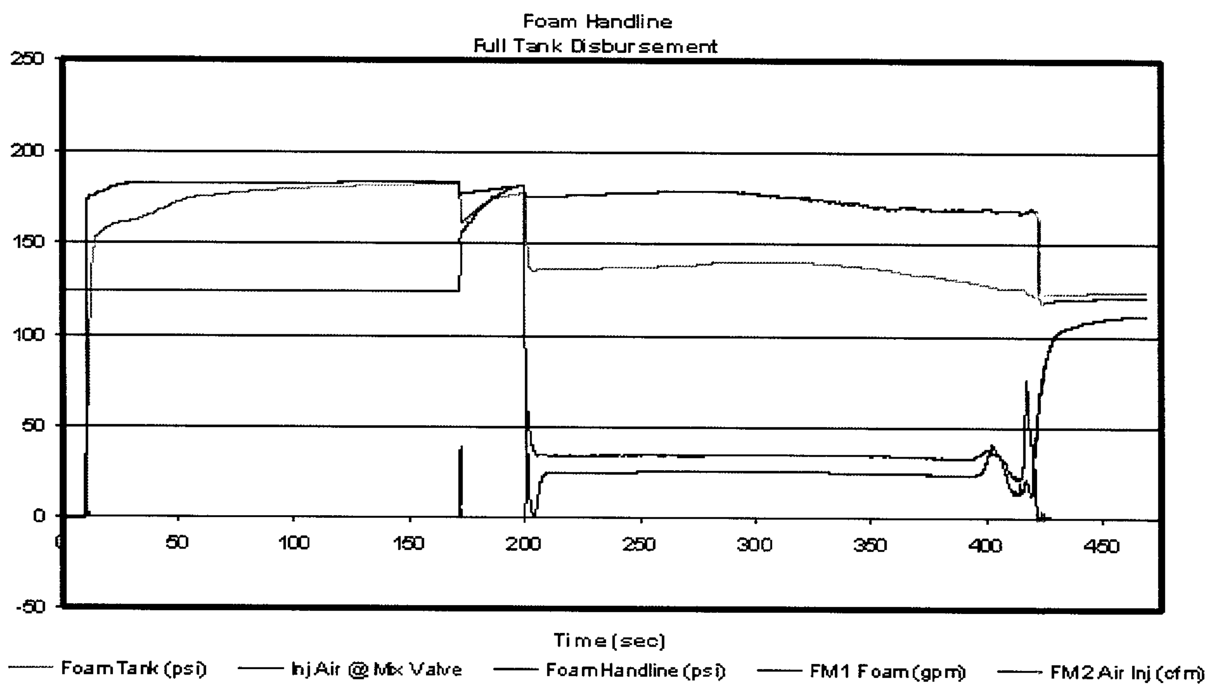

Figure 4. Handline Foam Flow and Pressure Data, Full Tank Disbursement.

Figure 5 shows the pressures and flow rates after the regulators were changed. The foam tank pressure was 168 psi. When the test began the foam tank pressure dropped to 130 psi, continued to climb to 161 psi, stabilized for a period of approximately 20 seconds, then climb until the end of the test to approximately 170 psi. The injection air pressure fell to 106 psi when the test began but steadily climb throughout the test and at the end of the test the injection air pressure was 174 psi. The foam flow rate decreased from 41 gpm to 33 gpm over the test duration. The injection airflow started around 6 cfm and increased to 12 cfm, however, toward the end of the test the cfm dropped again to approximately 7 cfm. The injection air became readable when the injection air pressure was within approximately 8 psi of the foam tank press.

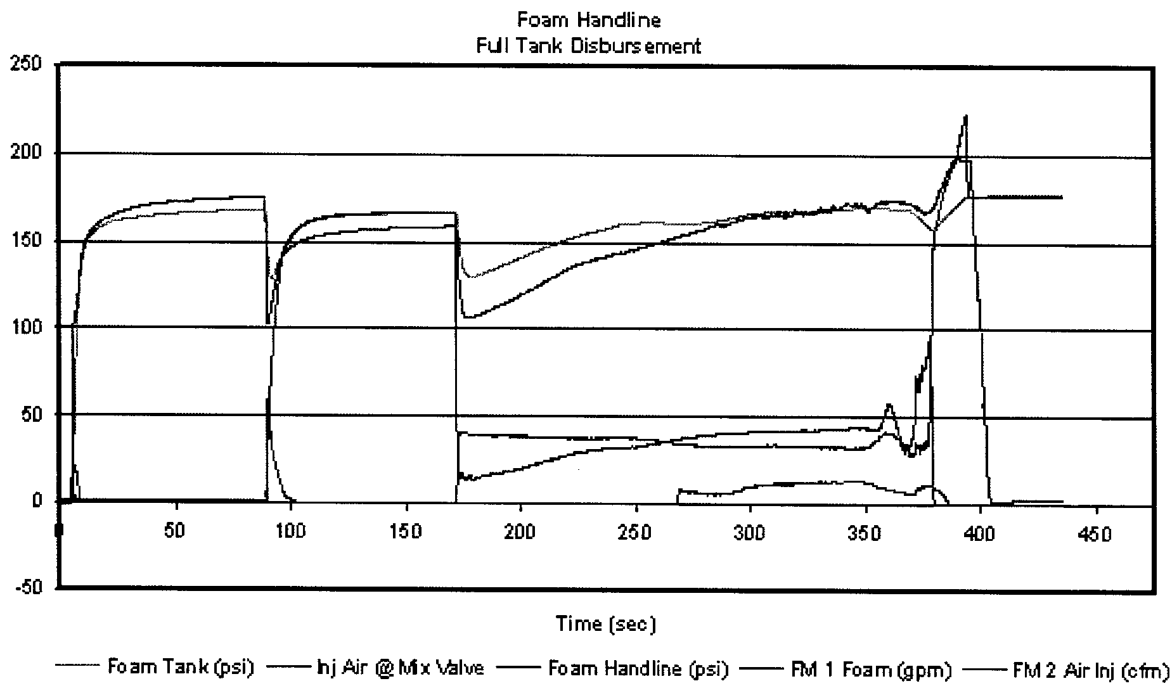

Figure 5. Handline Foam Flow and Pressure Data, Full Tank Disbursement.

3.1.3 Throw Distance and Width, Handline

The handline throw distance was measured at an angle of 30-degrees. The throw distance before the regulator was changed was 70', with a 9' 8" width and 70', with a width of 6'7". The throw distance measured after the regulators were change was approximately 90'.

3.1.4 Expansion Ratio, Handline

The average foam expansion ratio for the handline was 8.95, 5.8 and 5.5 prior to the change of regulators. After the change the average expansion ratio was 4.5. NFPA 412, air-aspirated AFFF should have a minimum expansion ratio of 5:1.

3.2 System Performance Foam Turret

3.2.1 System Performance for Foam Turret Intermittent Disbursement

Figure 6 shows the pressures and flow rates prior to the change of regulators. The foam tank regulator was adjusted from 200 psi to 185 psi per the manufacturer, however, over a period of 100 seconds the pressure increased to 193 psi. This indicated that the regulator on the foam tank was not working properly. When the test began the tank pressure steadily decreased from 118 psi, phase 1, to 89 psi, phase 4. The pressure at turret stayed relatively constant at 14 psi for the duration of testing. The foam flow showed only a decrease of 5 gpm from 67.4 to 62 gpm over the full discharge. The injection air flow averaged 20 cfm.

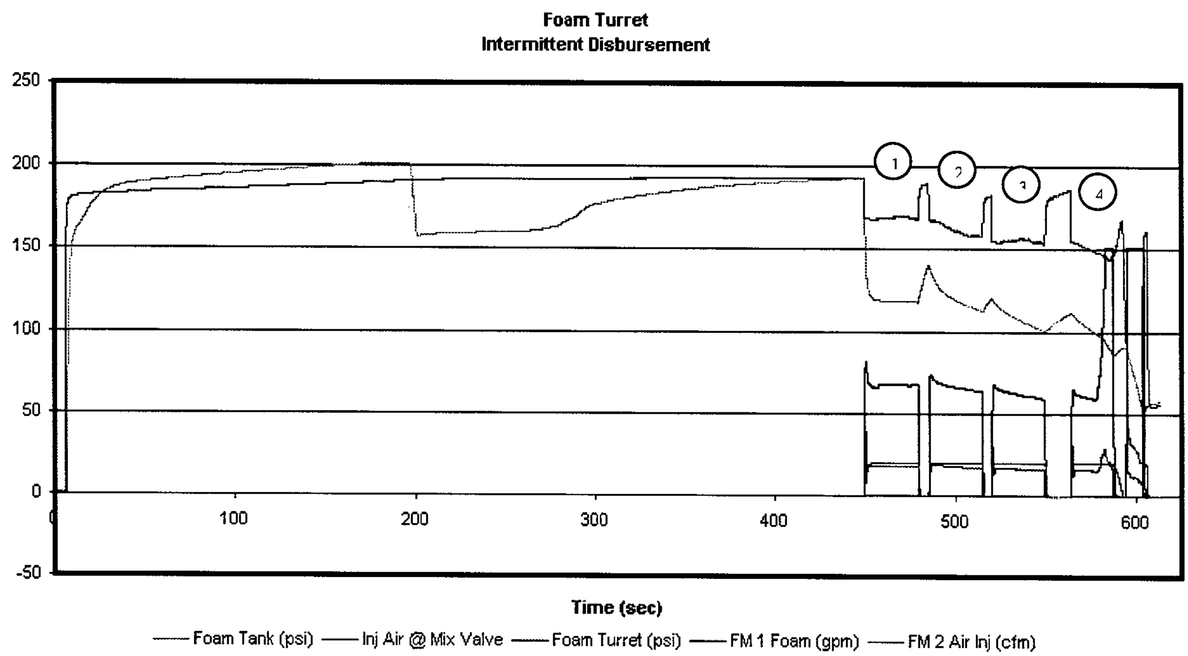

Figure 6. Turret Foam Flow and Pressure Data, Intermittent Disbursement.

Figure 7 shows the pressures at the foam air tank after the regulators were changed. A drop in foam high pressure air tank occurred toward the end of the test. Problems with instrumentation would have caused a negative reading and therefore, was ruled out as the source. The exact cause of the drop in pressure was never determined and continued to occur with both foam and dry chemical testing. Prior to the drop the injection air pressure had increase from 140, phase 1, to 160 psi, phase 3 (Figure 8). The pressure at the turret during flow remained stable at 16-18 psi. The foam flow meter registered a flow rate of 70 gpm, phase 1, to 85 gpm, phase 3. The injection air flow meter stayed relatively constant at 18 cfm.

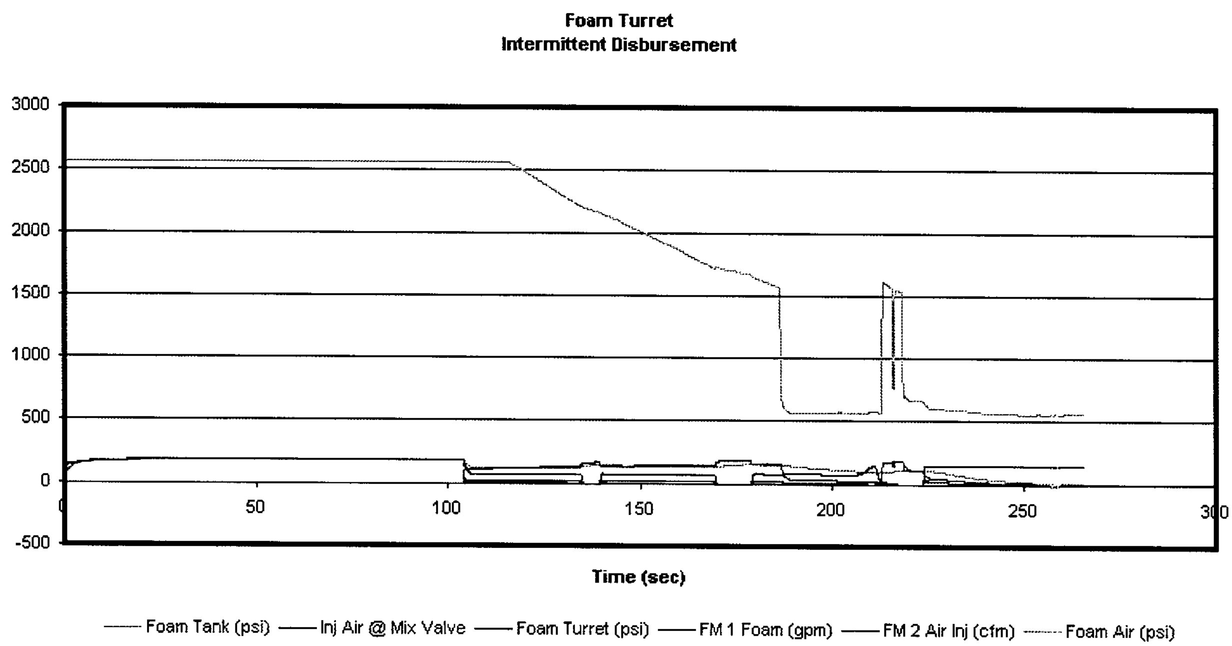

Figure 7. Foam Air Pressure Data, Intermittent Disbursement.

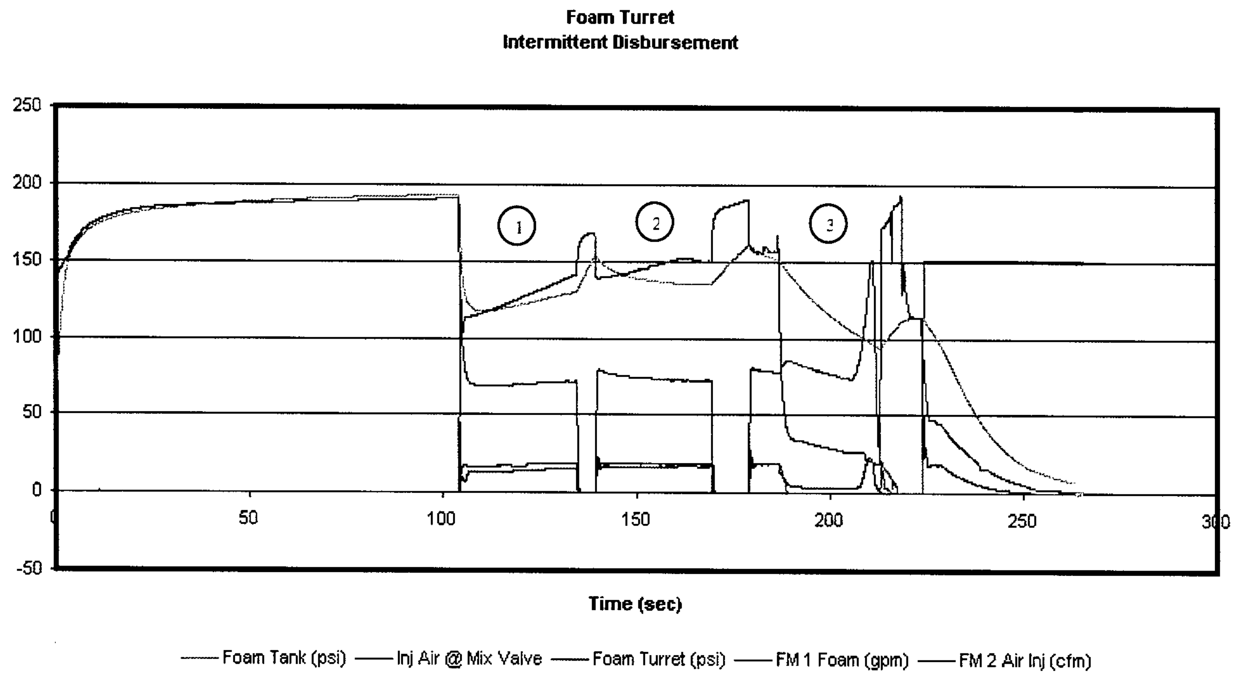

Figure 8. Turret Foam Flow and Pressure Data, Intermittent Disbursement.

3.2.2 System Performance for Foam Turret Full Tank Disbursement

Figure 9 shows the pressures and flow rates prior to the change of regulators. The foam tank pressure dropped from 190 psi to 118 psi during the full tank discharge. The pressure in the foam tank was not maintained and a steady decrease was observed for the full discharge. This suggests that a restriction exists in the system. The most likely source was the regulators since several other problems were experienced with that component, however, this was not confirmed by AFRL. The injection air pressure dropped from 186 to 152 psi. The foam flow during the first 27 seconds was approximately 64 gpm and steadily decreased to 53 gpm at the end of the test. The injection air stayed constant at 19 cfm. The pressure at the turret was consistent at 15-17 psi.

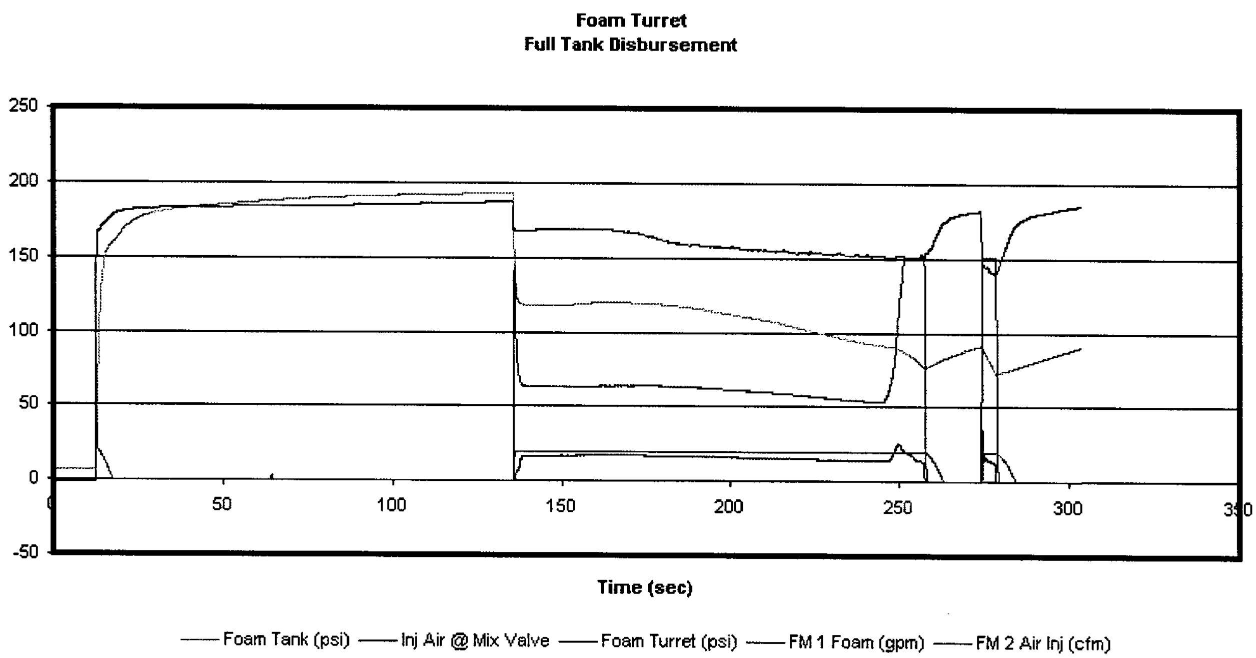

Figure 9. Turret Foam Flow and Pressure Data, Full Tank Disbursement.

Figure 10 shows the pressure and flow after the regulators were changed. Even though the new regulators were set to the manufacturer's specified settings, the foam tank pressure and the air injection pressure never reached the set points. The foam tank pressure reached 172 psi, decreased to 114 psi as the agent flowed then increased to 137 psi at the end. The injection air pressure increased to 167 psi after the initial drop of 106 psi. The foam flow was stable at 71 gpm, while the injection air meter maintained an approximate 23 cfm flow. The spike in the foam flow rate observed after the agent was depleted was likely due to the injection air that was still discharging, causing a faulty measurement. The turret pressure showed an increase from 12 to 19 psi. The injection air pressure continued to climb slightly even after the agent was depleted.

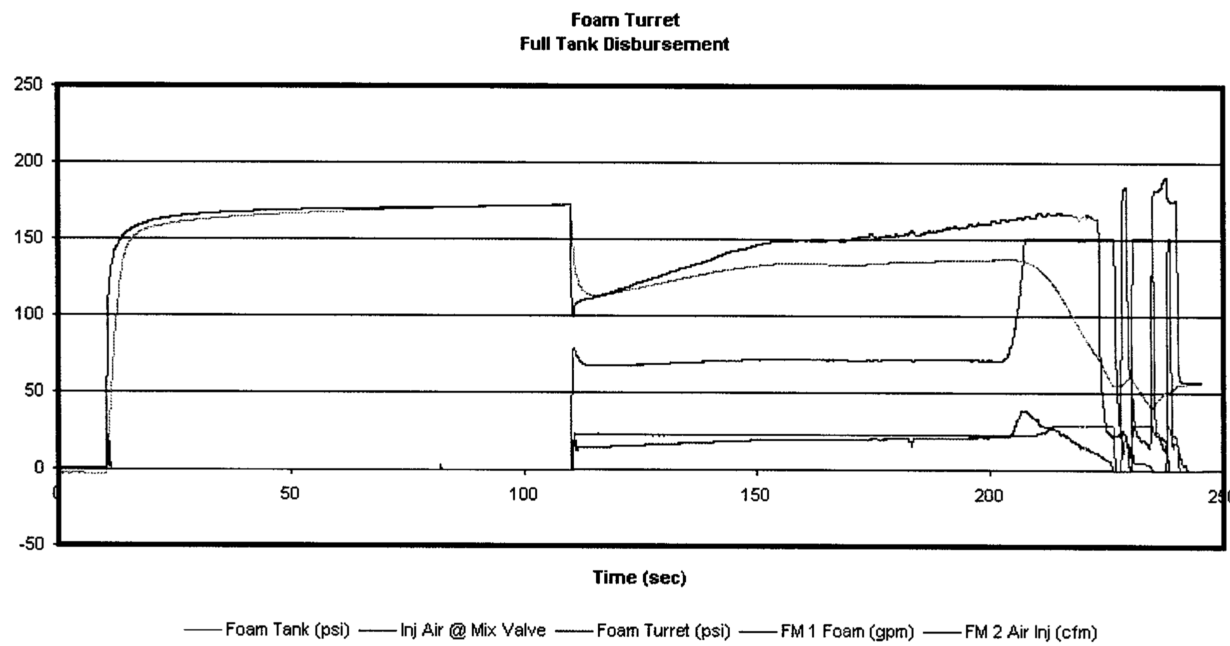

Figure 10. Turret Foam Flow and Pressure Data, Full Tank Disbursement.

3.2.3 Throw Distance and Width, Turret

The turret throw distance was measured at an angle of 30-degrees. The throw distance before the regulator was changed was 77', with a 19' width. The throw distance measured after the change was 85' 2", with a width of 10' 3".

3.2.4 Expansion Ratio, Turret

The average foam expansion ratio for the turret was 7.0 prior to the change of regulators and 6.4 after the change. NFPA 412, air-aspirated AFFF should have a minimum expansion ratio of 5:1.

3.2.5 Overall Foam System Performance

Problems with pressure regulation occurred on most tests and the system was slow to charge before the pressure regulators were changed. After the regulators were changed the previous problems continued and new problems such as unexplained drops in air tank pressure and pressure build-up in foam tank and injection air tank that resulted in the pop-off valve blowing. Throw distance, flow rates and expansion ratios were all within acceptable ranges.

3.3 System Performance for Dry Chemical Disbursement

3.3.1 Overall Dry Chemical System Performance

During each test of the dry chemical system, the pressure at the dry chemical tank was readjusted to 225 psi per manufactures specification. Pressures climbed past the 225 psi set point on the dry chemical tank resulting in the pop-off safety valve blowing at 250 psi.

Pressure drops at the foam and dry chemical air tanks occurred that could not be explained. The foam air tank decreased in pressure during test even though no foam was being flowed. A schematic was not provided to detail the plumbing and instrumentation layout of the system. The manufacturer provided information that stated that the foam and dry chemical systems were plumbed independently with it's own high pressure air source. The injection air for the foam also feeds off of the foam high pressure tank.

During turret full tank disbursement, the high pressure air volume was not sufficient to discharge the 500 lb capacity of the tank. This resulted in more than 50% of the dry chemical left in the tank unusable.

3.3.2 System Performance for Dry Chemical Handline Intermittent Disbursement

Figure 11 shows the pressures and flow rates prior to the change of regulators. The dry chemical tank pressure prior to the opening of the handline was approximately 209 psi. Five phases were completed during this test. The pounds per second used for each phase of the test averaged 3, 3, 4.2, 2.6 and 1. When the handline was charged, the pressure dropped to 189 psi and quickly climbed (time 5 seconds) to 192 psi. For the first three phases of flow testing, the dry chemical tank pressure remained at 175 psi. During the last two phases, the pressure dropped to 169 and 143 psi respectively. During non-flow periods the pressure remained between 191-201 psi. During the first two flow periods the handline pressure was approximately 54 psi, however, as the flow rate decreased the pressure on the handline increased to 60-70 psi.

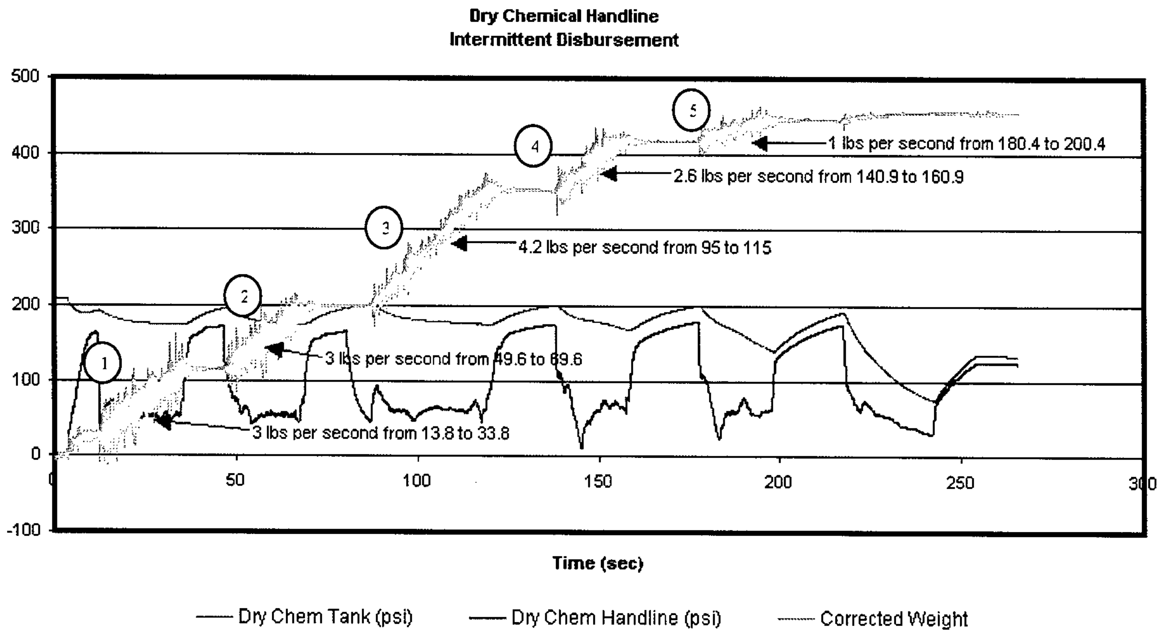

Figure 11. Handline Dry Chemical Flow and Pressure Data, Intermittent Disbursement

Figure 12 shows the pressures and flow rates after the regulators were changed. During the four test phases, the dry chemical flow rate was more consistent and averaged 3.4, 2.2, 2.6 and 2.4. The dry chemical tank pressure exceeded the 225 psi set point during the test and had to be manually corrected prior to the next test. The pressure dropped from 242 to 214 psi when the handline was charged and remained at this pressure until the test began. During the flow period the dry chemical tank pressures were 161, 164, 170, and 77 psi and during non-flow periods the pressures were 174, 196, 211 and 278 psi. When the dry chemical tank pressure reached 278 psi the system was cut off. Figure 13 shows the foam and the dry chemical air tank pressures during this test. The foam air tank continued to loose pressure throughout the test, while at the beginning of the test the dry chemical air tank increase slightly. During the test, the foam air tank was also decreasing in pressure and after the test had ended the foam air tank continued to loose pressure, which indicated that the foam air tank was still feeding the dry chemical tank. Again, the foam and dry chemical systems are independent of one another according to the manufacturer although they behave as though they are connected. The handline pressure, when the handline was charged was approximately 177 psi and varied during agent flow. During phase 1 the flow pressure fell from 67 to 58 psi; phase 2, 58 to 53 psi; phase 3, 61 to 57 psi; and phase 4, 70 to 34 psi. The non-flow periods the handline pressure was 107, 157, 91 to 114, and 138 psi.

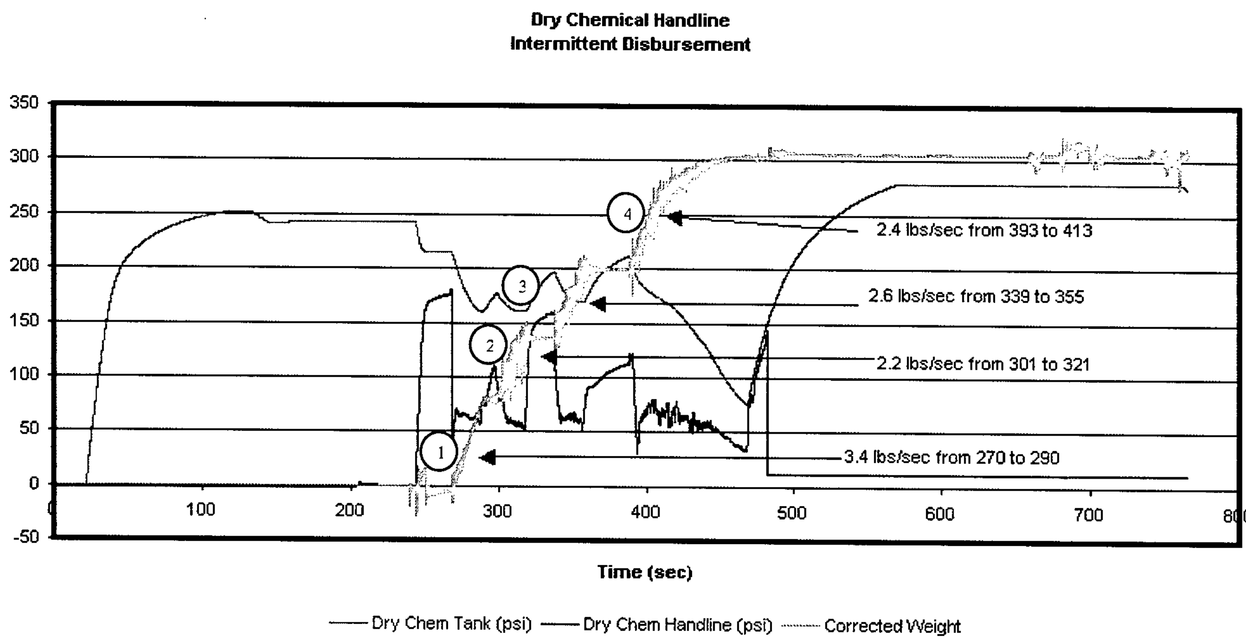

Figure 12. Handline Dry Chemical Flow and Pressure Data, Intermittent Disbursement.

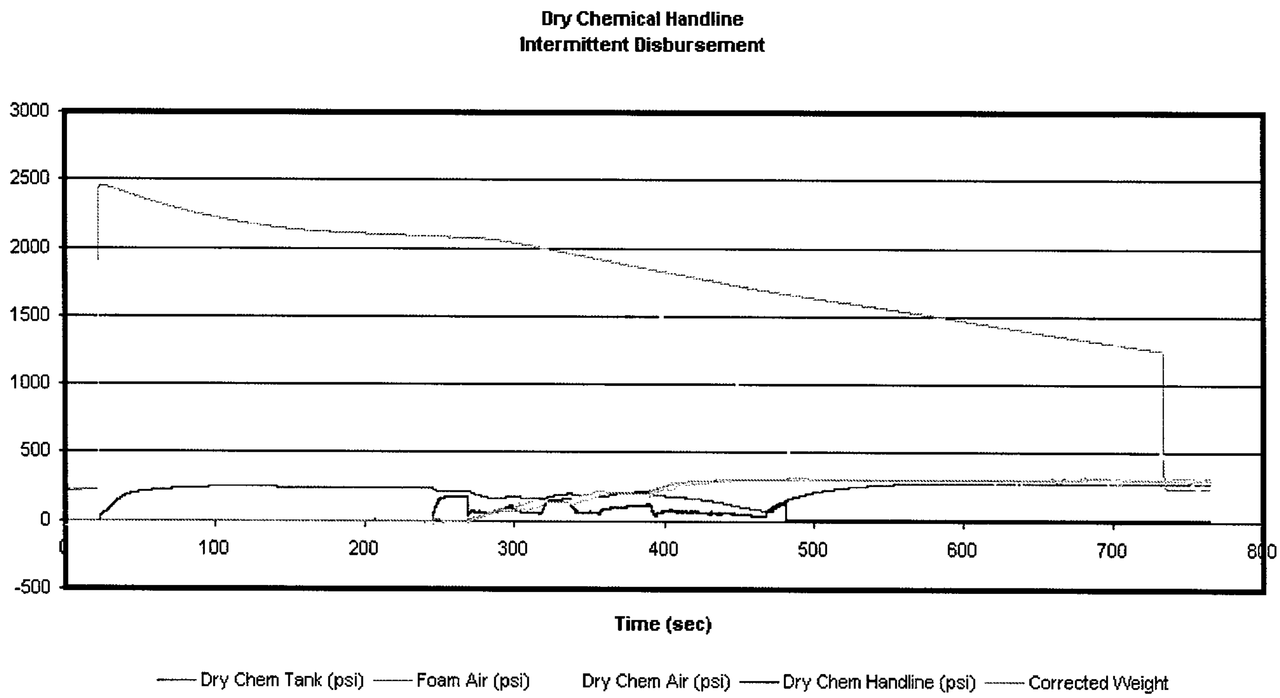

Figure 13. Air Tank Pressure Data, Intermittent Disbursement.

3.3.3 System Performance for Dry Chemical Handline Full Tank Disbursement

No dry chemical handline, full tank disbursement tests were conducted prior to the change of regulators. Figure 14 shows the air tank pressures for the foam air tank and the dry chemical air tank with the new regulators. Two drops in air pressure on the dry chemical air tank occurred during testing. One while the handline was charged, the other during agent flow. Flow and pressure measurements shown in Figure 15 do not indicate any change in the performance. Note that, as seen in the previous test, the foam air pressure continued to decrease throughout the test, while the dry chemical air increased slightly at the beginning. This indicated that the air from the foam air tank (higher pressure) was bleeding into the dry chemical air tank (lower pressure). The dry chemical tank pressure remained constant at 278 psi throughout the test even though the regulator was set at 225 psi. This constant pressure was not seen in any other test performed. The pressure on the handline nozzle was approximately 213 psi prior to the beginning of the test. When the test began, the average pressure on the handline was approximately 59 psi. The approximate discharge of dry chemical was three pps.

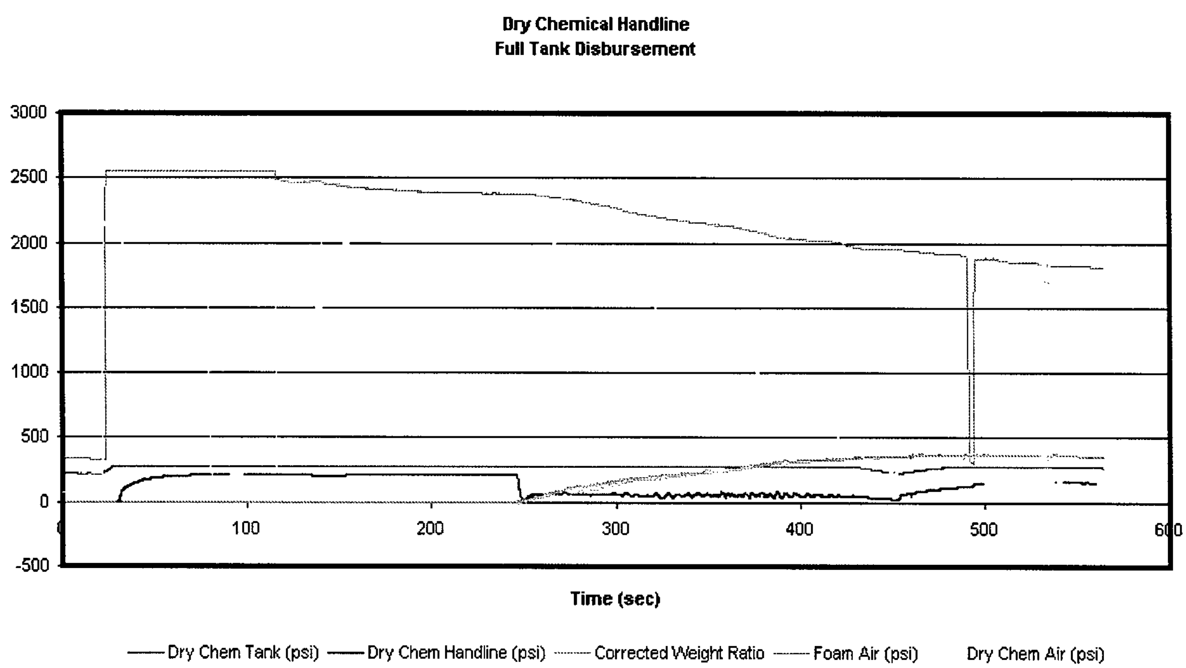

Figure 14. Air Tank Pressure Data, Full Tank Disbursement.

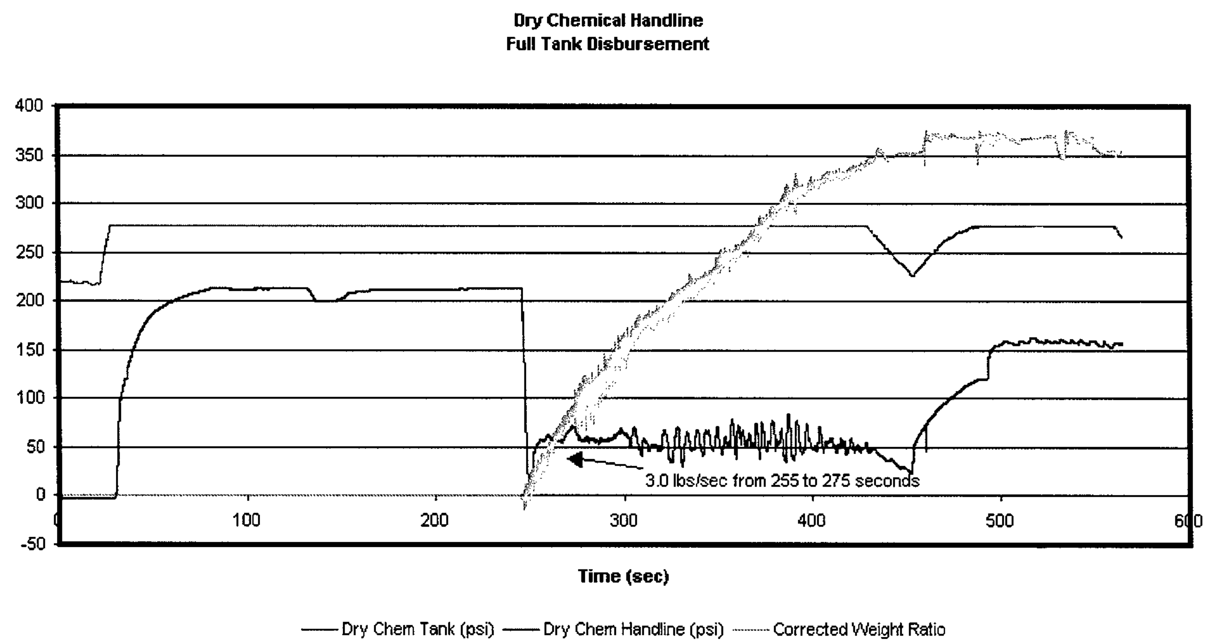

Figure 15. Foam Flow and Pressure Data, Full Tank Disbursement.

3.3.4 System Performance for Dry Chemical Turret Intermittent Disbursement

No tests were completed on the dry chemical turret prior to the change of the regulators. Figure 16 shows another unexplained pressure drop at the dry chemical air tank when the system was charged. The foam air tank showed a constant decline in pressure over the testing period. The dry chemical air tank showed a sharp drop in pressure after the system was charged. The dry chemical air tank pressure continued to drop until the dry chemical tank pressure (Figure 17) reached approximately 221 psi. At that point, the dry chemical air tank pressure started to increase until the agent was flowed. During each phase of the test the dry chemical air tank pressure continued to drop. The dry chemical tank pressure, once charged, increased to 238 psi. When the test began, the dry chemical tank pressure dropped to 171, 176, 152, 66 and 76 psi. The dry chemical tank pressures during non-flow periods were 198, 222, 212, 211 and 278 psi. The system was turned off at this point to prevent over pressurizing the system. The foam tank pressure during this test was 240 psi even though no foam was flowed. The turret pressures during phase 1, decreased from 97 psi to 73 psi and during phase 4 the pressure dropped from 93 to 20 psi. The dry chemical flow rate averaged 5.2, 4.5, 3.1, 0.6 and 0.5 pps. Little dry chemical was being disbursed after the third phase of the test even though only 262 lbs out of 500 lbs had been discharged. AFRL could not find an explanation for this result.

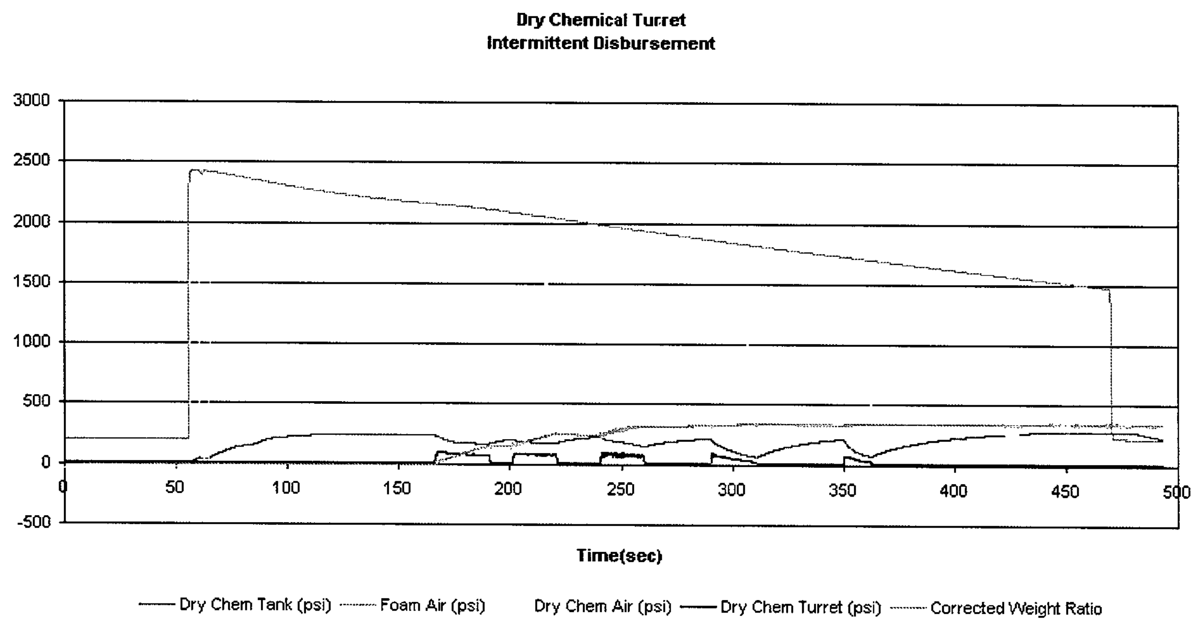

Figure 16. Air Tank Pressure Data, Intermittent Disbursement.

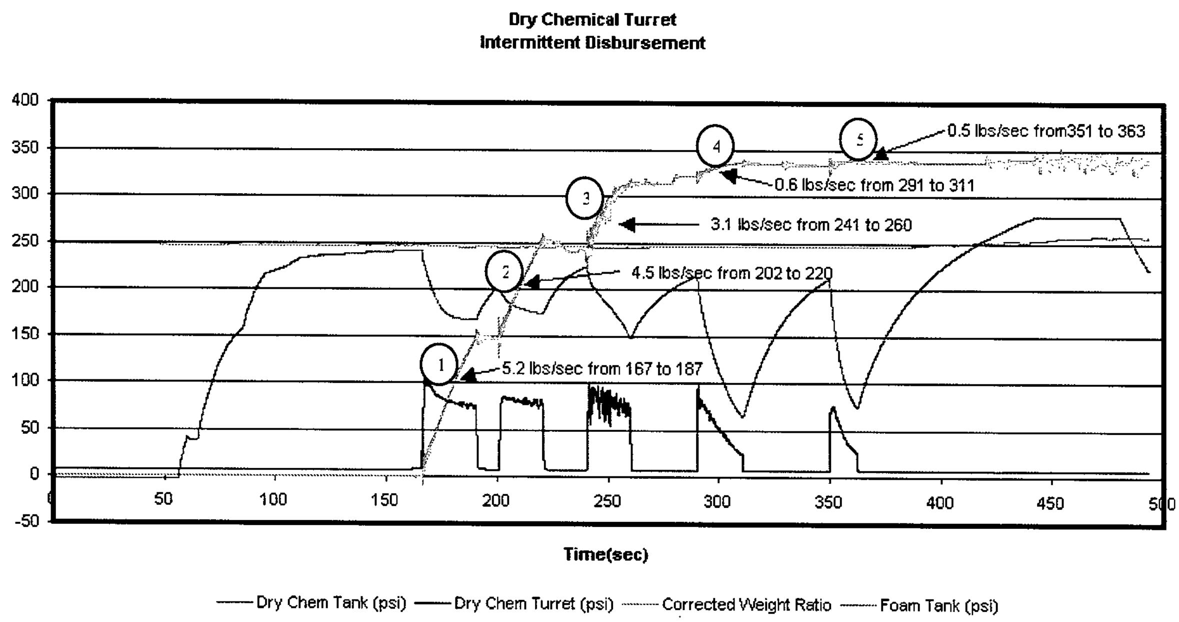

Figure 17. Foam Flow and Pressure Data, Intermittent Disbursement.

3.3.5 System Performance for Dry Chemical Turret Full Tank Disbursement

Figure 18 showed a drop in foam air tank pressure at both the beginning and end of the testing period. Over the testing period, the foam air tank pressure continued to drop. As with the previous testing, the dry chemical air tank pressure decreased until the dry chemical tank reached 235 psi, then increased in pressure until the test began. The foam tank pressure was maintained at 250 psi until the end of the test when the pressure increased to 261 psi (Figure 19). The dry chemical tank pressure reached 250 psi prior to the beginning of the test. The foam turret pressure decreased from 101 psi to 20 psi over the test period. The dry chemical used was approximately 4.9 lbs/sec (average from 172 to 202 seconds) for a total of approximately 147 lbs of the 500 lbs available. The majority of the dry chemical was not discharged before the pressure in the air tank was depleted. This significantly reduced the application time of the agent from 100 seconds (estimated) to 30 seconds (actual).

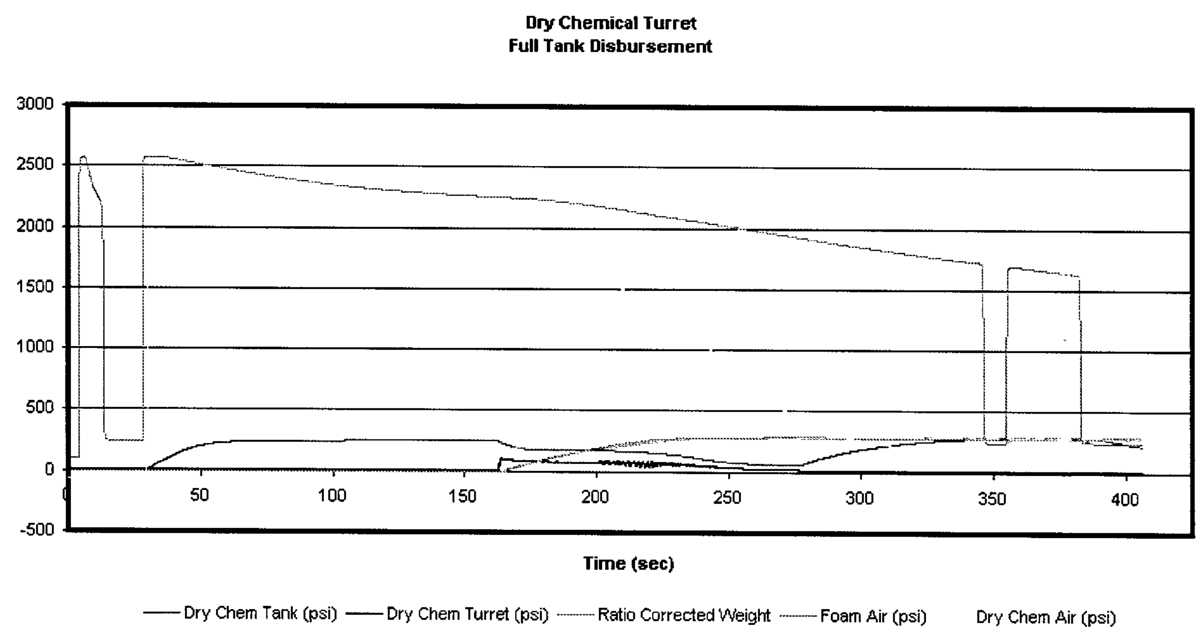

Figure 18. Air Tank Pressure Data, Full Tank Disbursement.

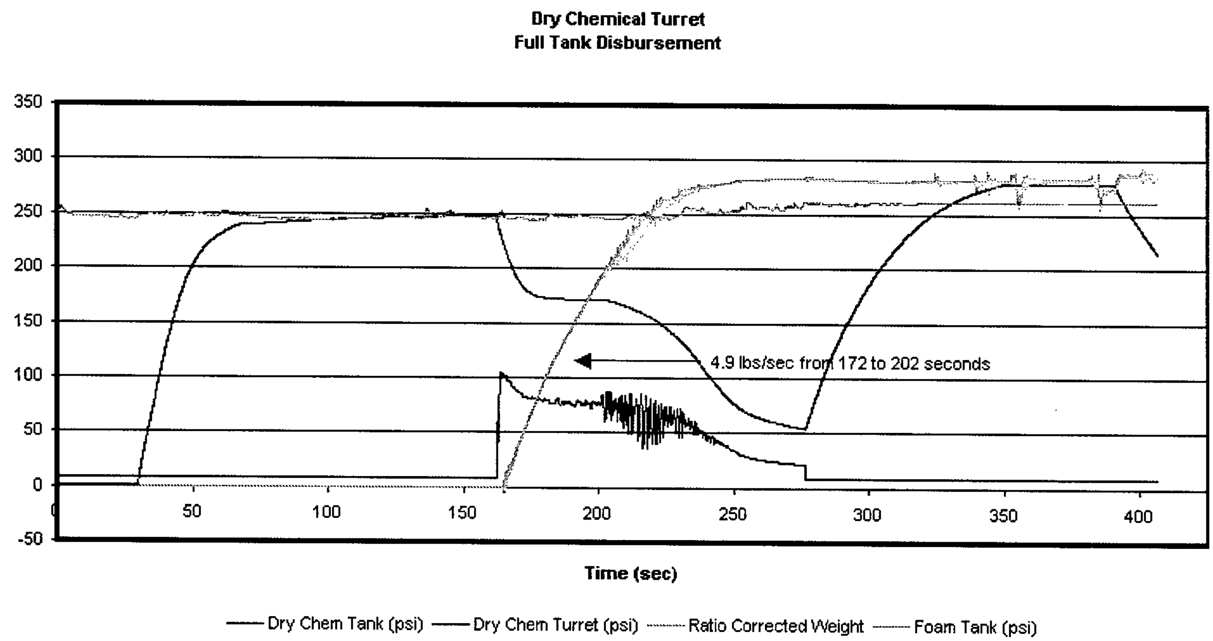

Figure 19. Foam Flow and Pressure Data, Full Tank Disbursement.

3.4 Combined Agent

3.4.1 Overall Combined Agent System

The foam tank and dry chemical tank pressures had to be adjusted prior to performing most tests. Additional increases in pressure on the dry chemical tank before, during and after testing resulted in the relief valve blowing. Decreases in pressure at the dry chemical tank and foam air tank were also recorded.

3.4.2 System Performance for Combined Agent Handline Disbursement

Figure 20 shows the pressures and flow rates prior to the change of regulators. The initial dry chemical tank pressure was 237 psi and decreased to 219 psi when the handline was charged. The foam tank pressure increased to 167 psi before the handline was charged indicating a leak in the regulator. The foam flow rate was approximately 35 gpm and the dry chemical flow rate was 2.7 pps.

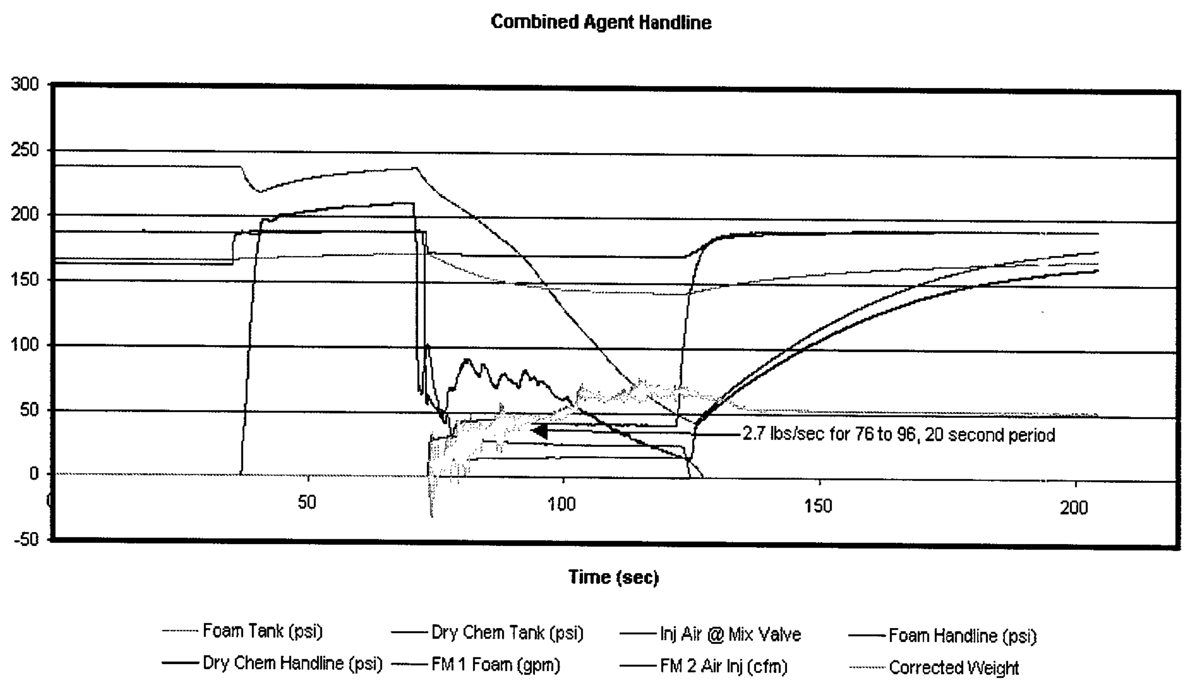

Figure 20. Foam Flow and Pressure Agent, Combined Agent Handline Disbursement.

Figure 21 shows the pressures and flow rates after the change of regulators. The adjustments to the foam tank pressure and dry chemical pressure are seen on the data prior to the test start. After the test was completed, the foam tank pressure continued to build. The pressure in the foam tank increased to over 280 psi before the system was shut down manually. This not only indicated a problem with the regulator but also a problem with the pressure relief valve, which is suppose to activate at 250 psi. This is a serious safety concern and should be addressed in future systems. The amount of dry chemical flow rate averaged 4.2 pps.

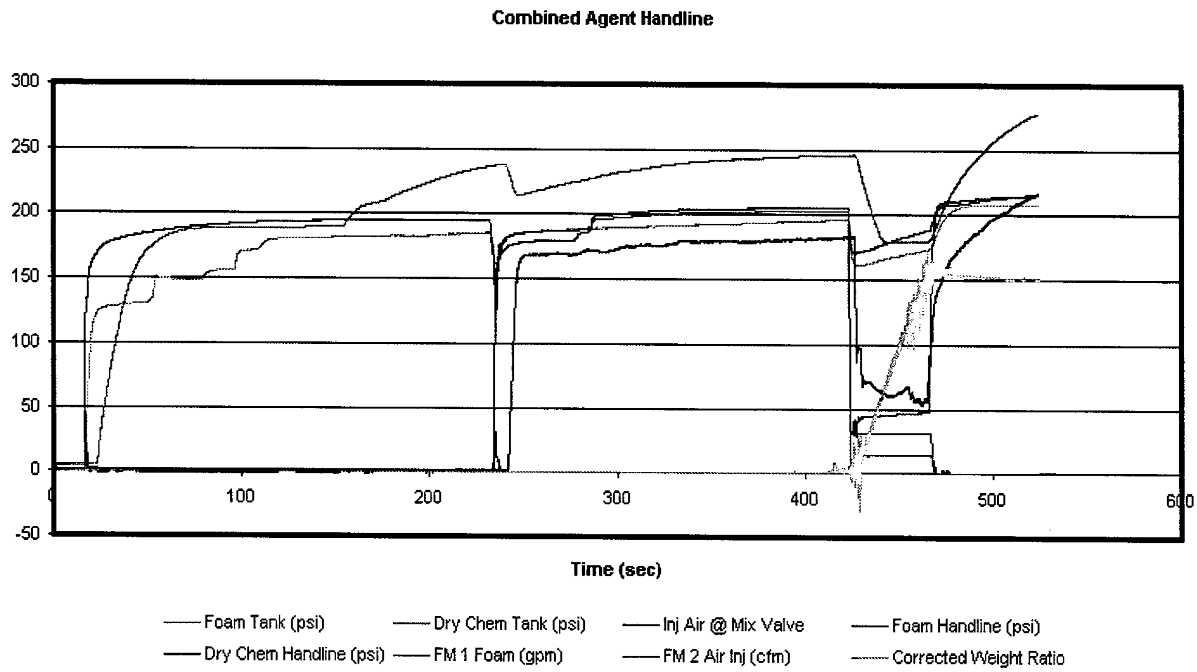

Figure 11. Foam Flow and Pressure Data, Combined Agent Handline Disbursement.

3.4.2.1 Throw Distance and Width

The combined agent, handline throw distance was measured at an angle of 30-degrees. The throw distance before the regulator was changed was 97' 1". The throw distance measured after the change was 114' 7".

3.4.2.2 Expansion Ratio

Expansion ratio tests were not performed on the combination agent tests because dry chemical degrades the foam blanket and the measurement could not be taken.

3.4.3 System Performance for Combined Agent Turret Disbursement

Figure 22 shows the foam flow and pressure data for the combined agent test prior to the change of regulators. The foam flow averaged 55 gpm and the dry chemical flow averaged 5.63 pps. The foam tank pressure was maintained throughout the test at approximately 120 psi while the dry chemical tank pressure steadily decreased from 240 psi to 180 psi.

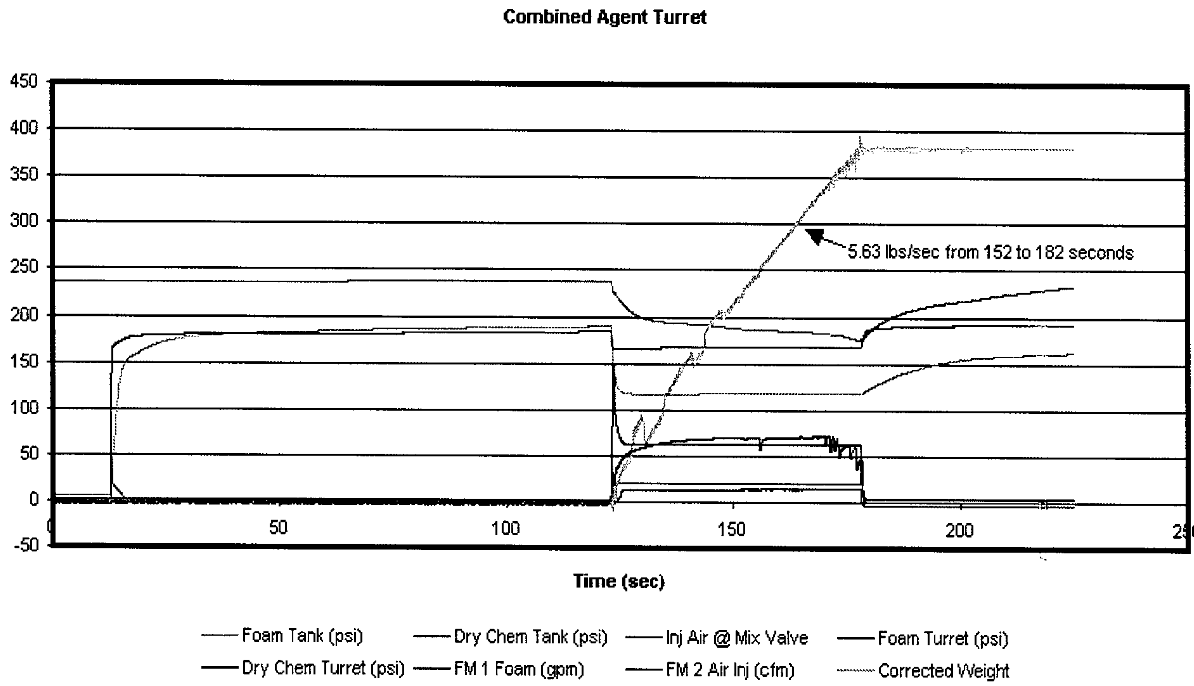

Figure 22. Foam Flow and Pressure Data, Combined Agent Turret.

Figure 23 shows the foam flow and pressure data after the regulators were changed. Foam flow rate decreased with the replacement regulators from 55 gpm to 20 gpm. The dry chemical flow rate stayed the same at 5.5 pps. The pressure on the dry chemical tank decreased from 250 psi to 170 psi during testing. The foam tank pressure increased slightly from 125 psi to 130 psi.

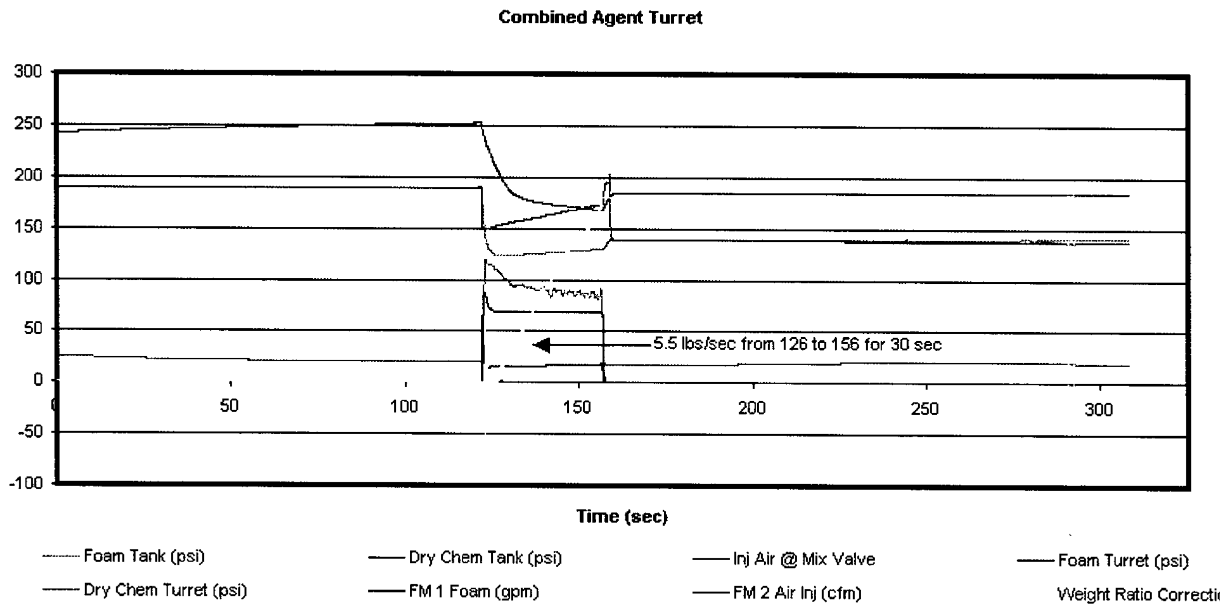

Figure 23. Foam Flow and Pressure Data, Combined Agent Disbursement.

3.4.3.1 Throw Distance and Width

The combined agent, turret throw distance was measured at an angle of 30-degrees. The throw distance before the regulator was changed was 89' 4". The throw distance measured after the change was 94' 6".

3.4.3.2 Expansion Ratio

Expansion ratio tests were not performed on the combination agent tests because dry chemical degrades the foam blanket and the measurement could not be taken.

4 Conclusions

The overall performance of the EFSS was good. Expansion ratio, throw distance and flow rates were all within acceptable ranges. The majority of the problems experienced with the EFSS 5120-7 were a result of the regulators. While the manufacturer replaced the initial regulators with higher quality components, significant problems were still encountered. AFRL suggested the installation of filters in series with the regulators to keep debris from fouling the regulators. Extensive experience with other systems that operated with compressed air have shown that debris entrained in the compressed air during reservicing can cause complete failure of the regulators if the air is not filtered properly.

During several tests, the pop off valve did not activate at the set pressure. This valve was the only safety device installed on the system to relieve pressure in the event of regulator failure. AFRL had to manually shut down the EFSS during testing to avoid over pressuring the foam and dry chemical tanks.

The foam system needs to be evaluated to determine why that part of the system is activated when the dry chemical system is being discharged. According to the manufacturer, the systems are plumbed as stand alone and should not operate unless agent is being flowed.

Currently, less than 50% of the total dry chemical volume was discharged with the amount of compressed air available.

5 Recommendations

The function and safety of the EFSS relies heavily on the performance of the regulators. Experience during testing has shown that faulty regulators make the system inoperable from a reliability and safety standpoint. High quality regulators should be installed on the system along with a set of filters to prevent debris from fouling the components. Additional safety measures may need to be taken since the regulators and pressure relief valves both failed on at least one test. Manufacturers recommend that regulators be rebuild every year. Experience in extreme environments, in particular sand, dust and dry chemical, indicates that more frequent overhauling is necessary to assure optimal performance.

The pop off valves should be checked for rating and proper function to prevent potential failure of the agent tanks due to over pressurization.

Complete a plumbing diagram so that each agent system can be evaluated and problems remedied.

The volume of compressed air need to drive the dry chemical turret operation needs to be recalculated.

6 Appendix

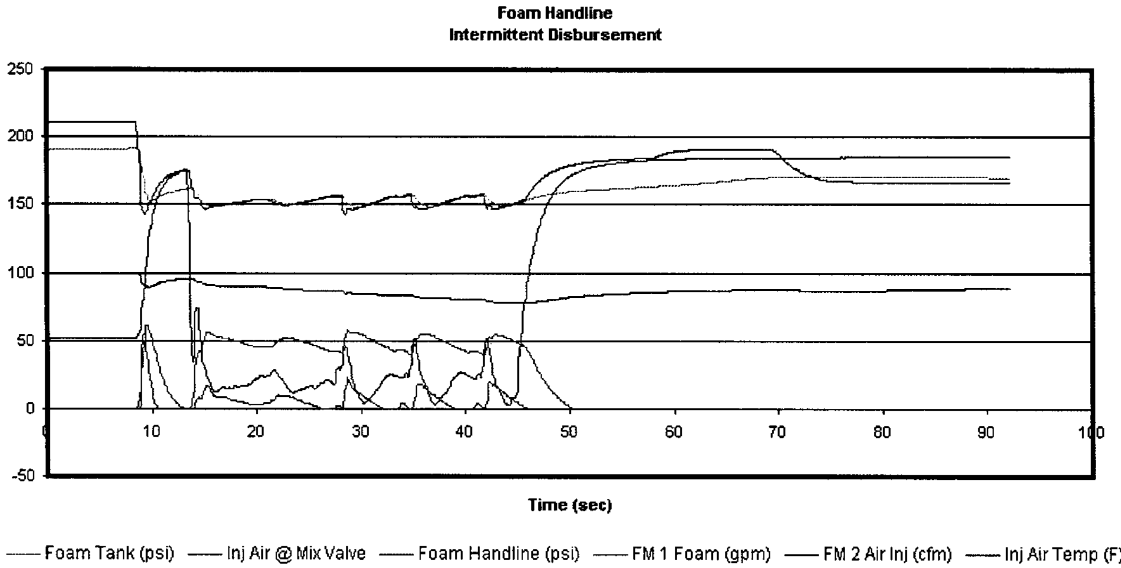

Figure 24. Test 2: Handline, Foam, Intermittent, Original Regulator.

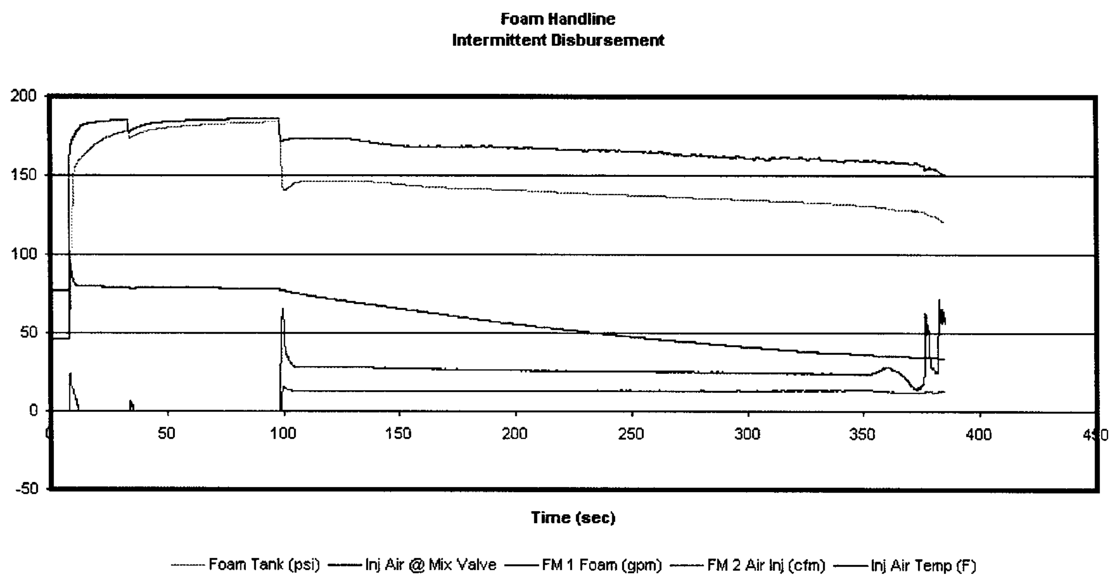

Figure 25: Test 3: Handline, Foam, Full Discharge, Original Regulator.

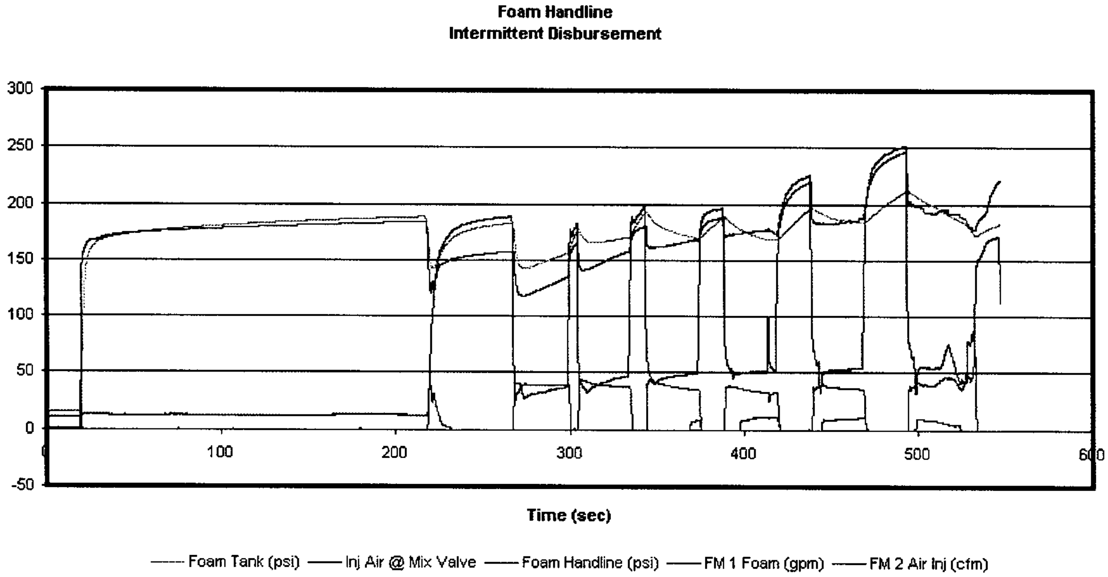

Figure 26. Test 7A: Handline, Foam, Intermittent, Replacement Regulator.

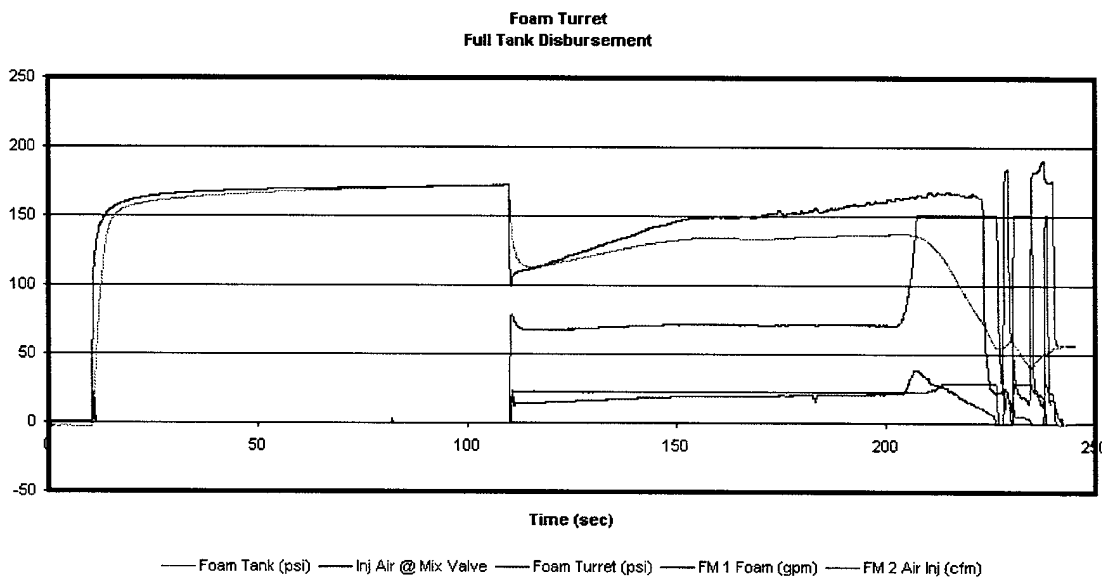

Figure 27. Test 10A: Turret, Foam, Full Discharge, Replacement Regulator.

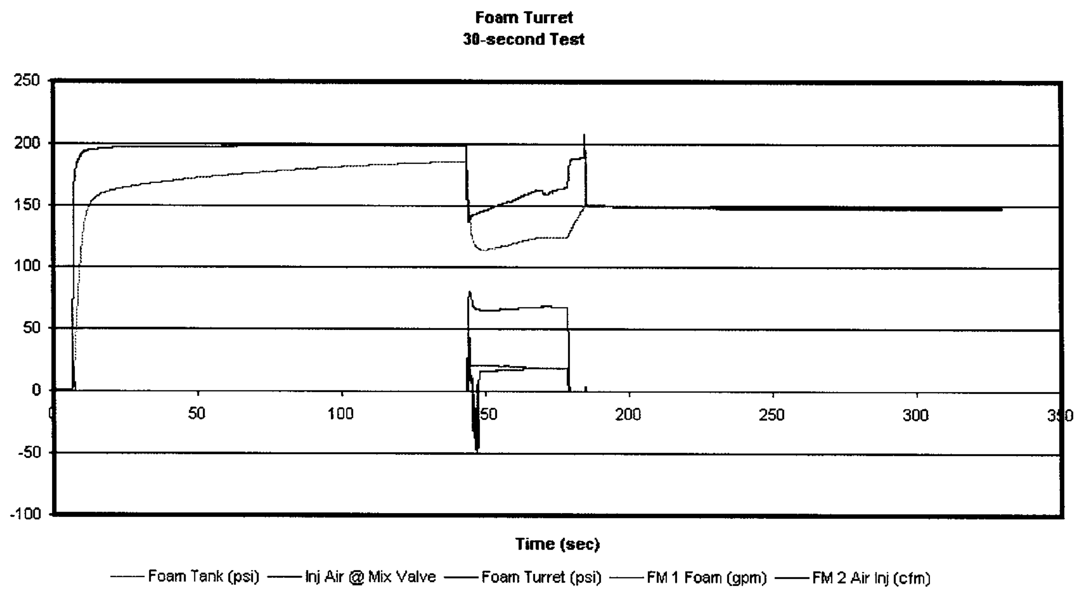

Figure 28. Test 18A: Turret, Foam, 30 Second Discharge, Replacement Regulator.

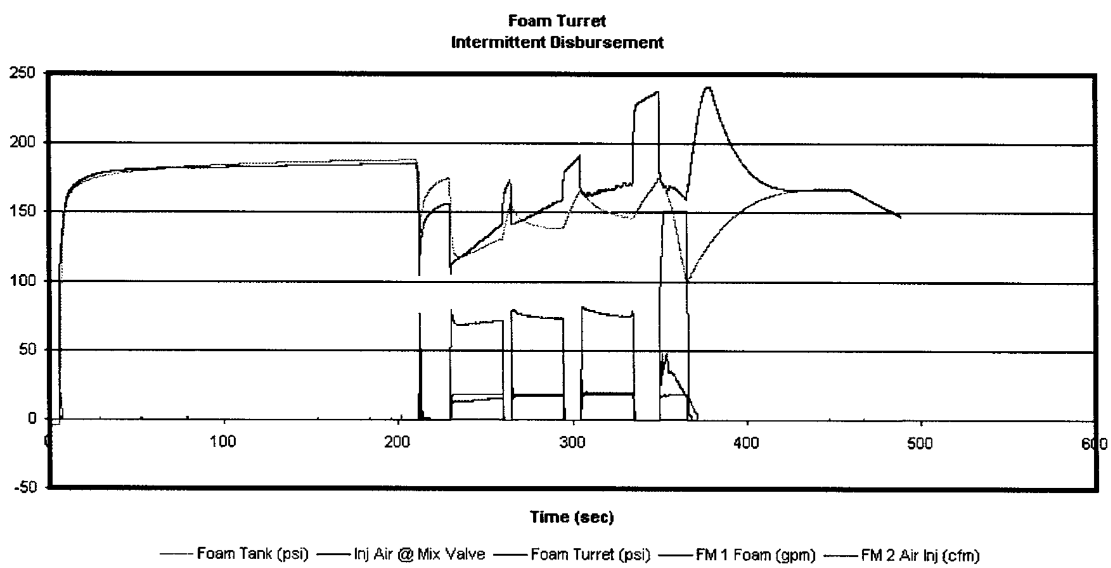

Figure 29. Test 6B: Turret, Foam, Intermittent, Replacement Regulator.

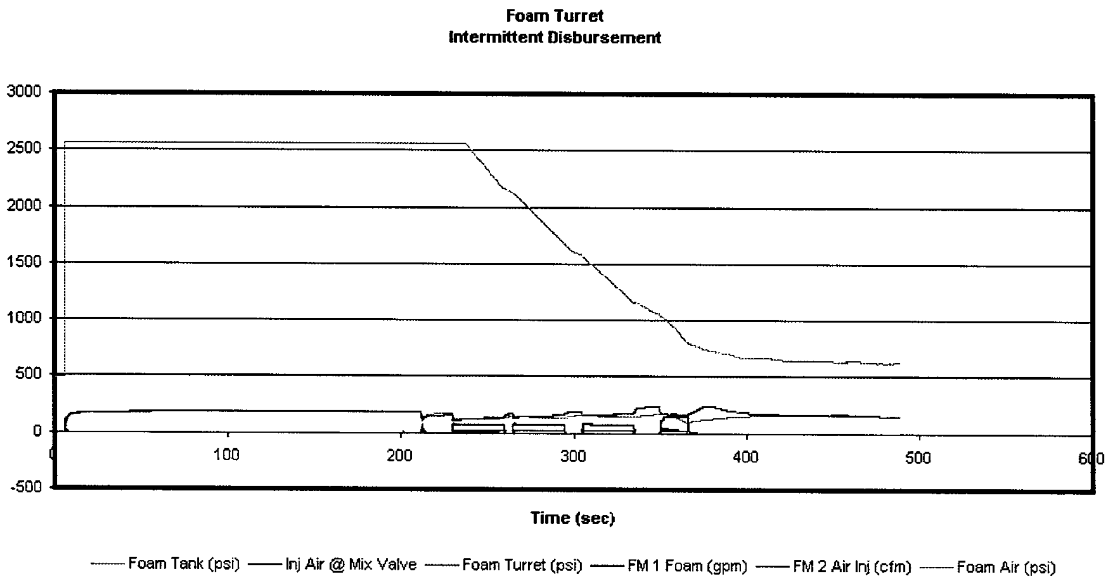

Figure 30. Test 6B: Turret, Foam, Intermittent, Replacement Regulator.

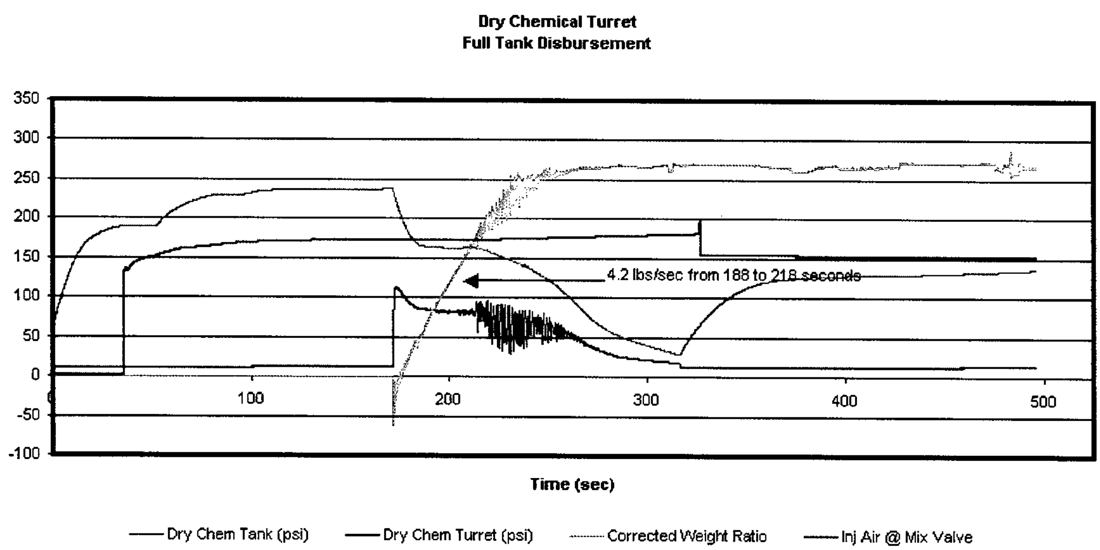

Figure 31. Test 20A: Turret, Dry Chemical, Full Discharge, Replacement Regulator.

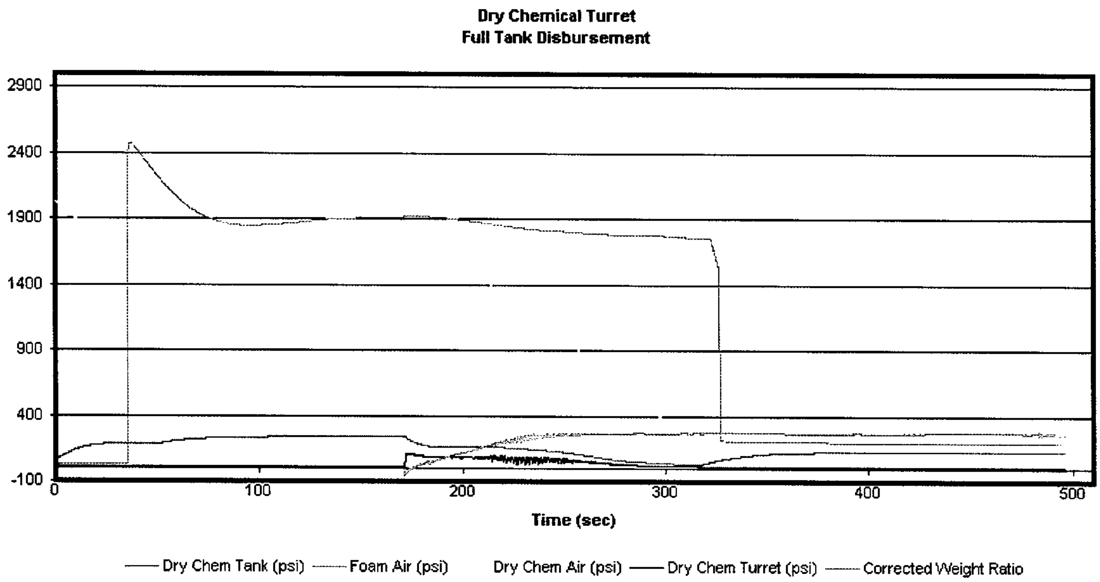

Figure 32. Test 20A: Turret, Dry Chemical, Full Discharge, Replacement Regulator.

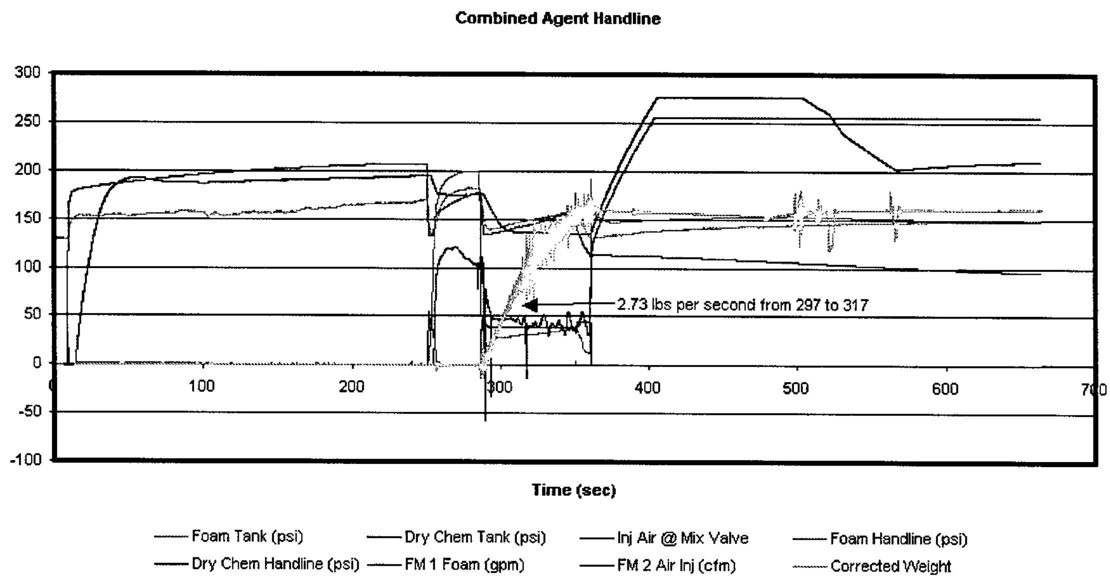

Figure 33. Test 11A: Handline, Combined Agent, Full Discharge, Replacement Regulator.

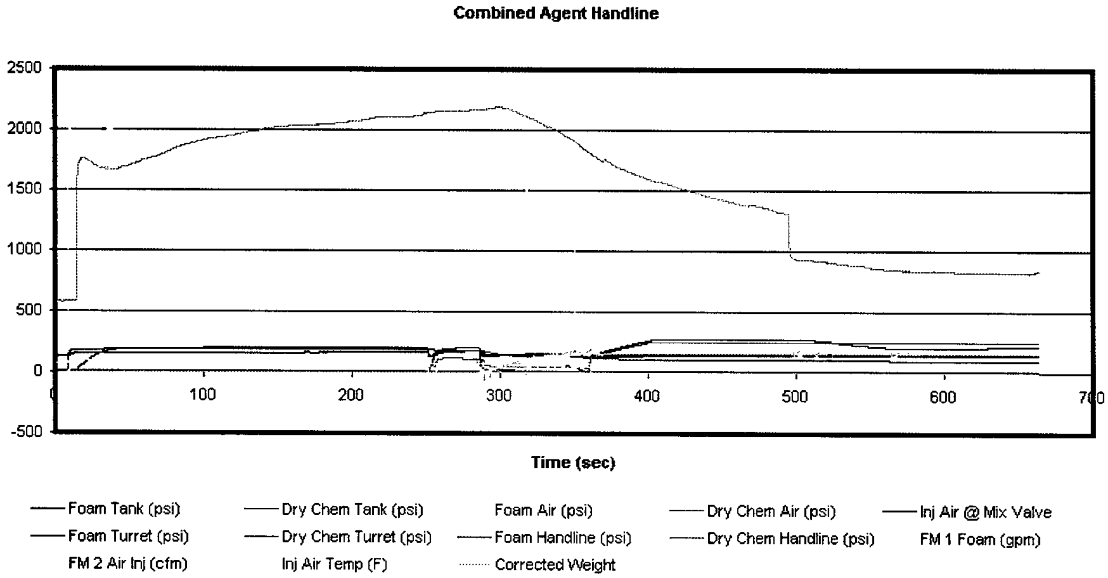

Figure 34. Test 11A: Handline, Combined Agent, Full Discharge, Replacement Regulator.

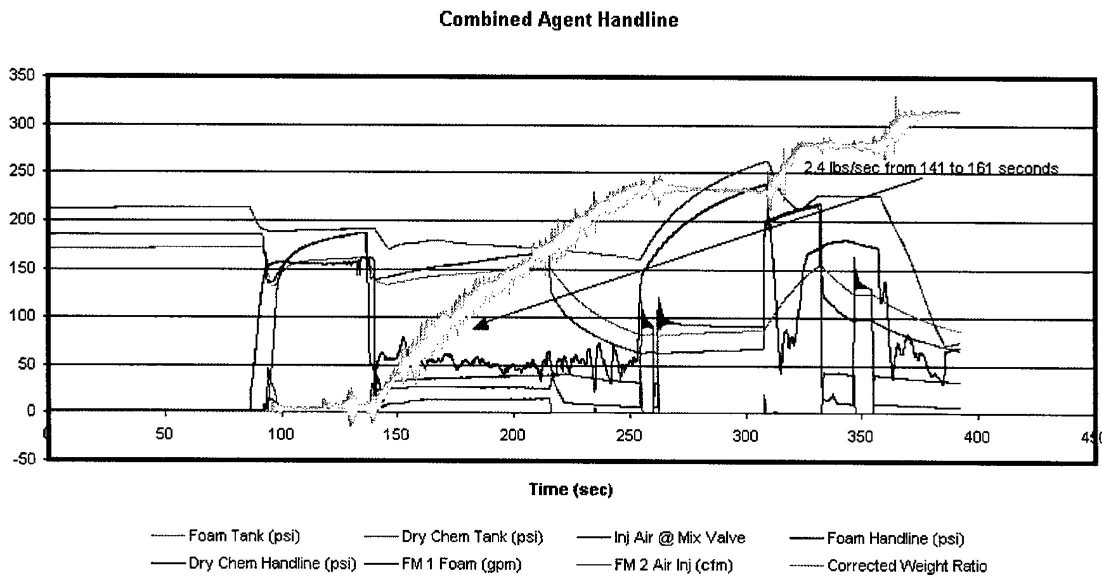

Figure 35. Test 13A: Handline, Combination Agent, Intermittent, Replacement Regulator.

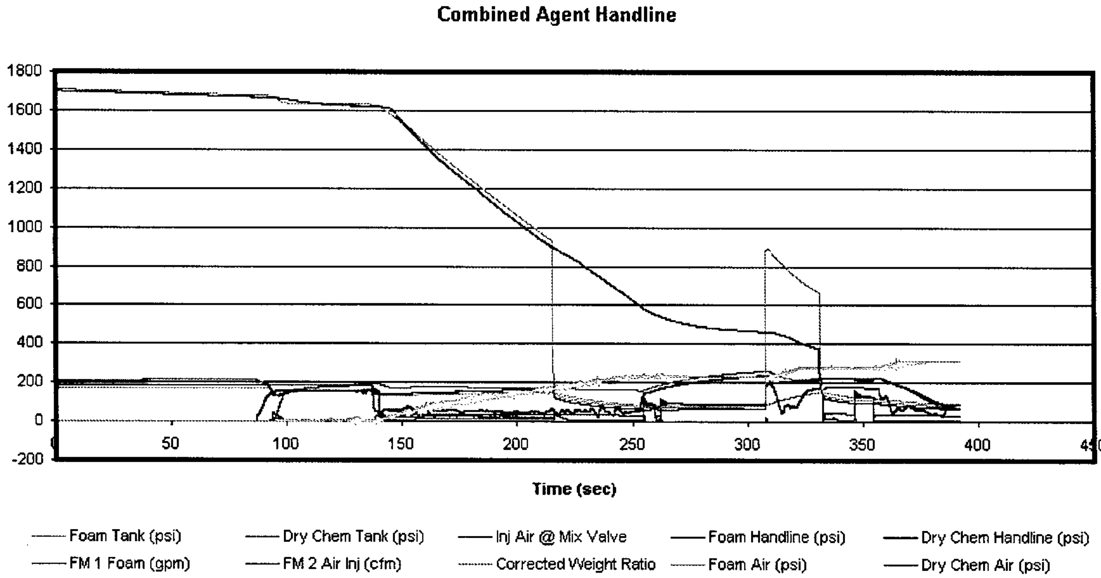

Figure 36. Test 13A: Handline, Combination Agent, Intermittent, Replacement Regulator.

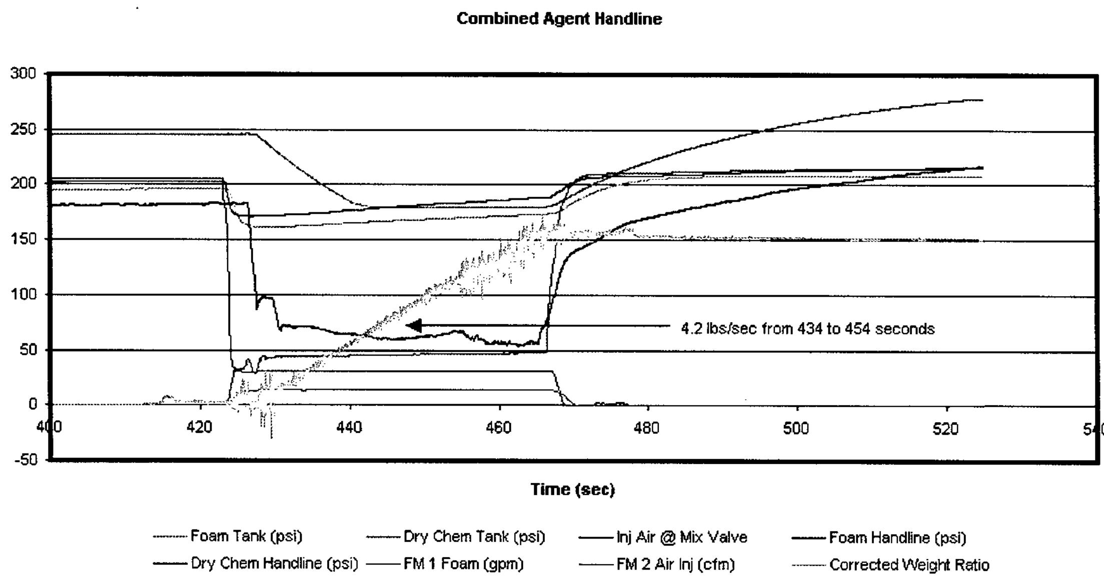

Figure 37. Test 17A: Handline, Combination Agent, 30 Second Discharge, Replacement Regulator.

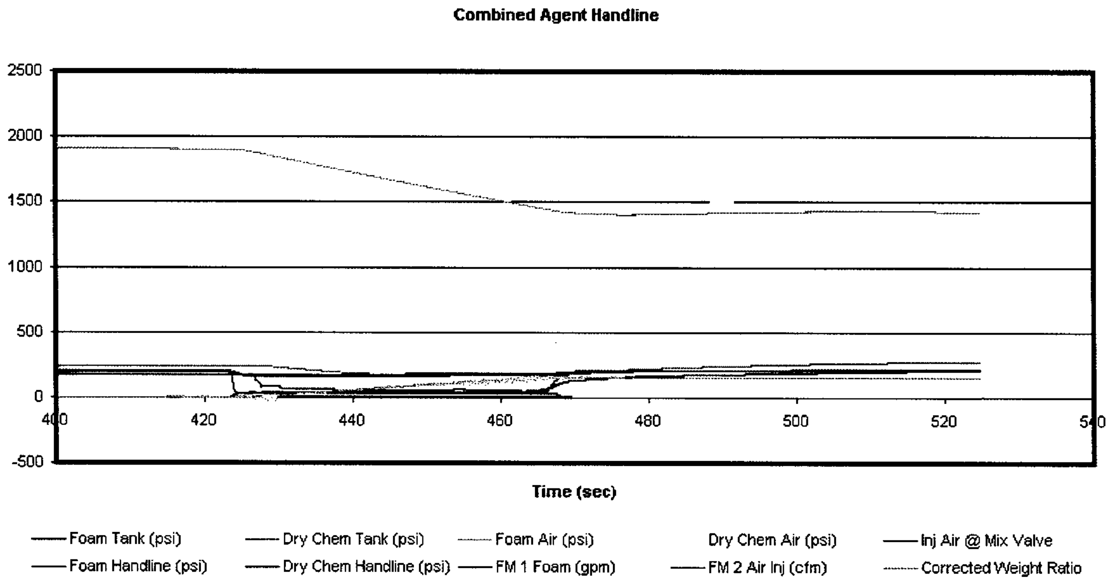

Figure 38. Test 17A: Handline, Combination Agent, 30 Second Discharge, Replacement Regulator.

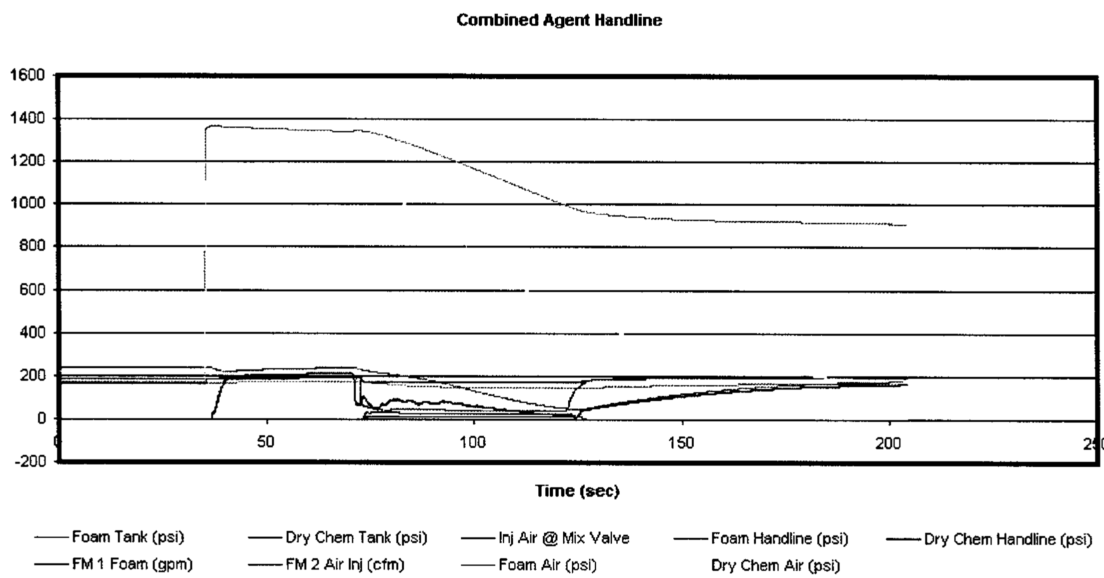

Figure 39. Test 9: Handline, Combined Agent, Full Discharge, Original Regulator.

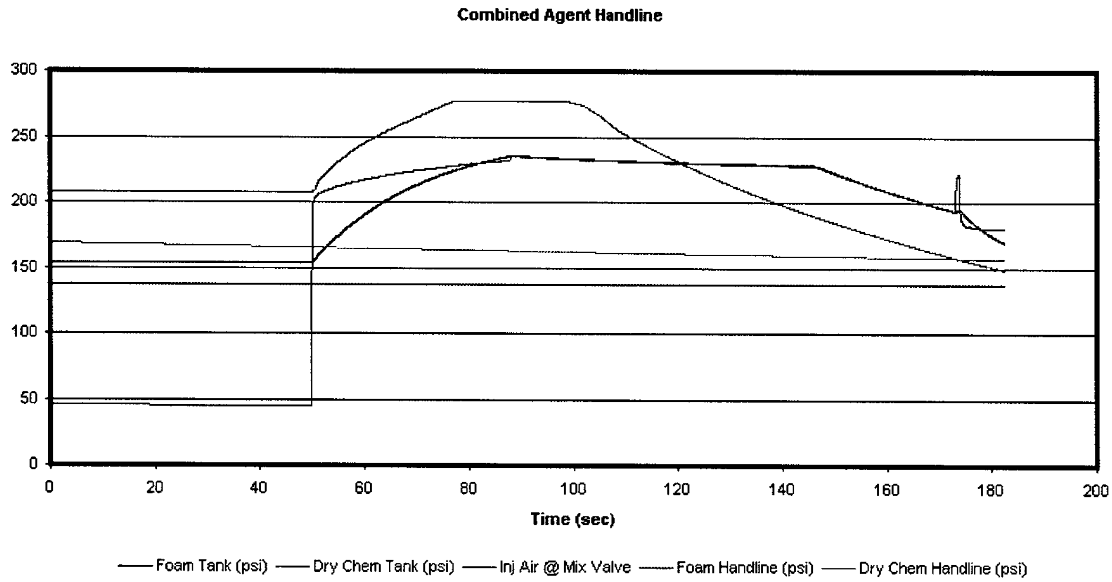

Figure 40. Test 12A: Handline, Combined Agent, Intermittent, Replacement Regulator.